SUPPLEMENTAL CLOSURE PLAN REPORT
SULLIVAN LANDFILL
SULLIVAN, MISSOURI

TES

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Sullivan Landfill PRP Group

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OCTOBER 1993

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SUPPLEMENTAL CLOSURE PLAN REPORT
SULLIVAN LANDFILL

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HAZARDOUS WASTE PROGRAM
MISSOURI DEPARTMENT OF NATURAL RESOURCES

TABLE OF CONTENTS

Section	Title	Page No.
1.0	INTRODUCTION	1-1
2.0	RESPONSE TO MDNR COMMENTS OF FEBRUARY 25, 1993	2-1
2.1	DESIGN OF VEGETATIVE SOIL LAYER	2-1
2.2	LINER DESIGN REFINEMENTS	2-1
2.3	INFORMATION ON VLDPE GEOMEMBRANE	2-2
2.4	REVIEW AND REVISION OF SEEP MANAGEMENT ALTERNATIVES	2-2
2.5	SINKHOLE TREATMENT DURING CLOSURE	2-6
2.5.1	Test Pit Findings	2-7
2.5.2	Delineation of Waste Area Limits	2-7
2.5.3	Stabilization of the Sinkhole Area	2-10
2.6	POST-CLOSURE GROUNDWATER MONITORING	2-12
2.7	FINANCIAL ASSURANCE	2-13
2.8	SETTLEMENT MARKERS	2-13
3.0	RESPONSE TO MDNR COMMENTS OF MAY 1993	3-1
4.0	CONCLUSION	4-1

GLOSSARY OF ACRONYMS AND ABBREVIATIONS

REFERENCES

APPENDICES

APPENDIX A	-	LEACHATE SEEP RATE CALCULATIONS
APPENDIX B	-	SINKHOLE PLAN, SECTIONS, AND DETAILS
APPENDIX C	-	MDNR AUGUST 16, 1993 COMMENTS LETTER ABB-ES SEPTEMBER 24, 1993 RESPONSE LETTER
APPENDIX D	-	STRESS EVALUATION CALCULATIONS

SUPPLEMENTAL CLOSURE PLAN REPORT
SULLIVAN LANDFILL

LIST OF FIGURES

Figure	Title	Page No.
1	Plan of Leachate Collection	2-3
2	Interceptor Trench Drain at Seeps	2-4
3	Precast Reinforced Concrete Holding Tank	2-5
4	Sinkhole Test Pit Locations 1 through 11	2-8
5	Sinkhole Sections 1 and 2	2-9
6	Test Pit Locations 12 through 40	2-11
7	Settlement Platform	2-15
8	Settlement Monitoring Locations	2-16

1.0 INTRODUCTION

ABB Environmental Services, Inc., (ABB-ES) prepared the Supplemental Closure Plan Report as an addendum to the Sullivan Landfill Closure Plan (ABB-ES, 1992b) to address the remaining technical issues identified by the Missouri Department of Natural Resources (MDNR) in their February 25, 1993 letter to ABB-ES. The Sullivan Landfill Closure Plan and this Supplemental Closure Plan Report together comprise the complete Closure Plan for the Sullivan Landfill, and are hereafter referred to as the Closure Plan. The objective of the Closure Plan is to incorporate the findings of the site investigation into a conceptual design for landfill closure. Closure consists of the following primary elements:

- leachate seep management
- sinkhole reinforcing system
- composite landfill cap
- post-closure groundwater monitoring

The Closure Plan addresses all of the issues raised by MDNR. Approval of the Closure Plan will allow the Sullivan Landfill investigation and closure project to move into the final design phase and allow closure implementation to occur in 1994.

Section 2.0 provides responses to the eight issues listed in MDNR's February 25, 1993 letter. Section 3.0 is the response to a request for information received from MDNR during a May 27, 1993 telephone call. Section 4.0 provides a conclusion to this Supplemental Closure Plan.

The resolution of the remaining issues and MDNR approval of the Closure Plan as well as the Site Investigation and Remedial Alternatives Study (SIRA) (see ABB-ES, 1993) will allow the Sullivan Landfill to move to final design. Timely Closure Plan approval by MDNR will assure that construction of the landfill cap, originally planned for 1993, can be completed within calendar year 1994.

2.0 RESPONSE TO MDNR COMMENTS OF FEBRUARY 25, 1993

The following subsections contain our responses to the eight issues raised by MDNR in February 1993.

2.1 DESIGN OF VEGETATIVE SOIL LAYER

Responding to the MDNR's request to consider water retention capacity of the landfill cap's six-inch vegetative soil layer proposed in the Closure Plan, ABB-ES contacted the U.S. Soil Conservation Service (USSCS) in Franklin County, MO. The USSCS was solicited for recommendations regarding soil layer thickness and for guidance related to choice of proper grass seed mixture given the relative dryness of the site's climate during summer months. Based on the recommendations of the USSCS, the following revisions were made to the Closure Plan:

1. The thickness of the vegetative soil cover layer will be increased to twelve inches to provide adequate moisture retention such that potential wilting of the vegetative cover is minimized.

2. The grass seed mixture will contain a fast-growing Kentucky 31 Tall Fescue capable of withstanding extended periods of both sparse and excessive rainfall.

3. The vegetative cover soil will be tested for nutrient content analysis at the University of Missouri soil testing laboratory.

Based on the test results, soil amendments may be added to promote sustained grass growth. These construction-related items will be developed in more detail during the final design phase.

2.2 LINER DESIGN REFINEMENTS

The MDNR requested that further refinement of geomembrane design be performed for various applications such as corners and bends. Because they are dependent on other aspects of the final cap design yet to be developed, details addressing treatment of geomembrane at these locations will be performed during final design. MDNR will have the opportunity for review at that time.

2.3 Information on VLDPE Geomembrane

MDNR requested that very low density polyethylene (VLDPE)-related references regarding installation, owners of facilities where the material has been installed, and regulatory official viewpoint be submitted. In response, ABB-ES submitted all requested information in an April 5, 1993 letter to MDNR.

2.4 Review and Revision of Seep Management Alternatives

In the January 20, 1993 Closure Plan comments letter provided by MDNR to ABB-ES, a request was made to abandon the concept of passive leachate seep remediation after cap placement in favor of active collection and disposal. Although ABB-ES believes that the seeps will evaporate if left exposed subsequent to capping the landfill, the timeframe for complete passive seep remediation cannot be estimated with certainty. To comply with MDNR's request, ABB-ES proposes the following active leachate seep remediation plan.

After placement of the hydraulic barrier soil component of the landfill cap, the seven leachate seeps will be pumped into vacuum trucks and disposed offsite at a commercial wastewater disposal facility. Concurrent with this effort, a piping/holding tank system will be constructed to collect for disposal seep flows occurring after cap construction. An estimated seep volume equal to the volume currently contained by the seven seep ponds (approximately 200,000 gallons total) is predicted to continue to flow over a period of from six to twelve months after cap placement. (Estimated leachate seep rate calculations are provided in Appendix A).

The system to collect leachate seep water will consist of gravity piping and four holding tanks. The leachate seeps will be drained by gravity piping to four holding tanks buried at the locations shown in Figure 1. One tank will be dedicated to receive flows from Seeps 1 through 4, while Seeps 5 through 7 drain to one dedicated tank each. A geomembrane liner will be constructed below and downgradient from the perforated pipe trench as shown in Figure 2 to preclude leakage of seep liquid. Holding tank detail is shown in Figure 3. Each tank will be sized to hold, at a

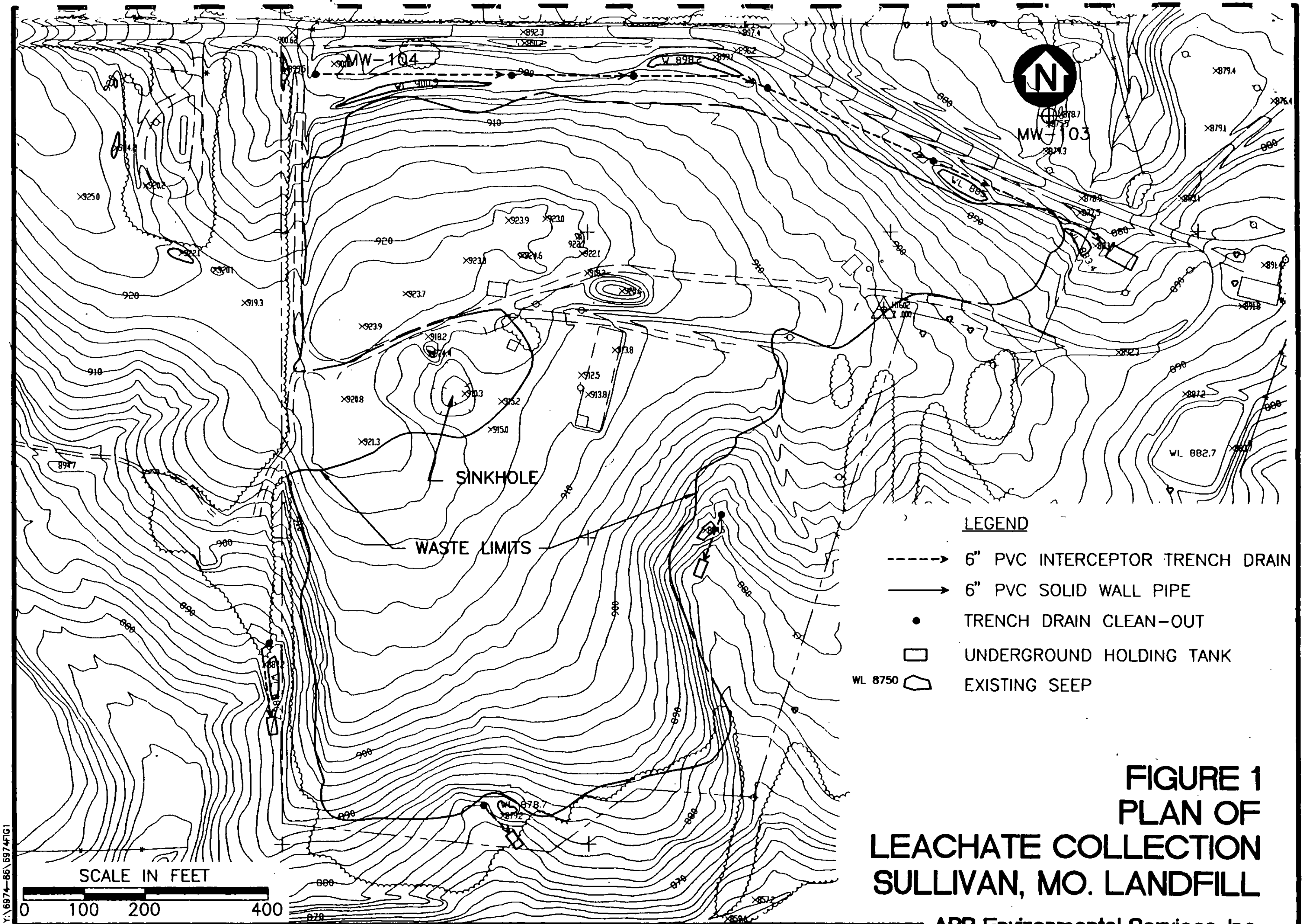


FIGURE 1
PLAN OF
LEACHATE COLLECTION
SULLIVAN, MO. LANDFILL

ABB Environmental Services, Inc.

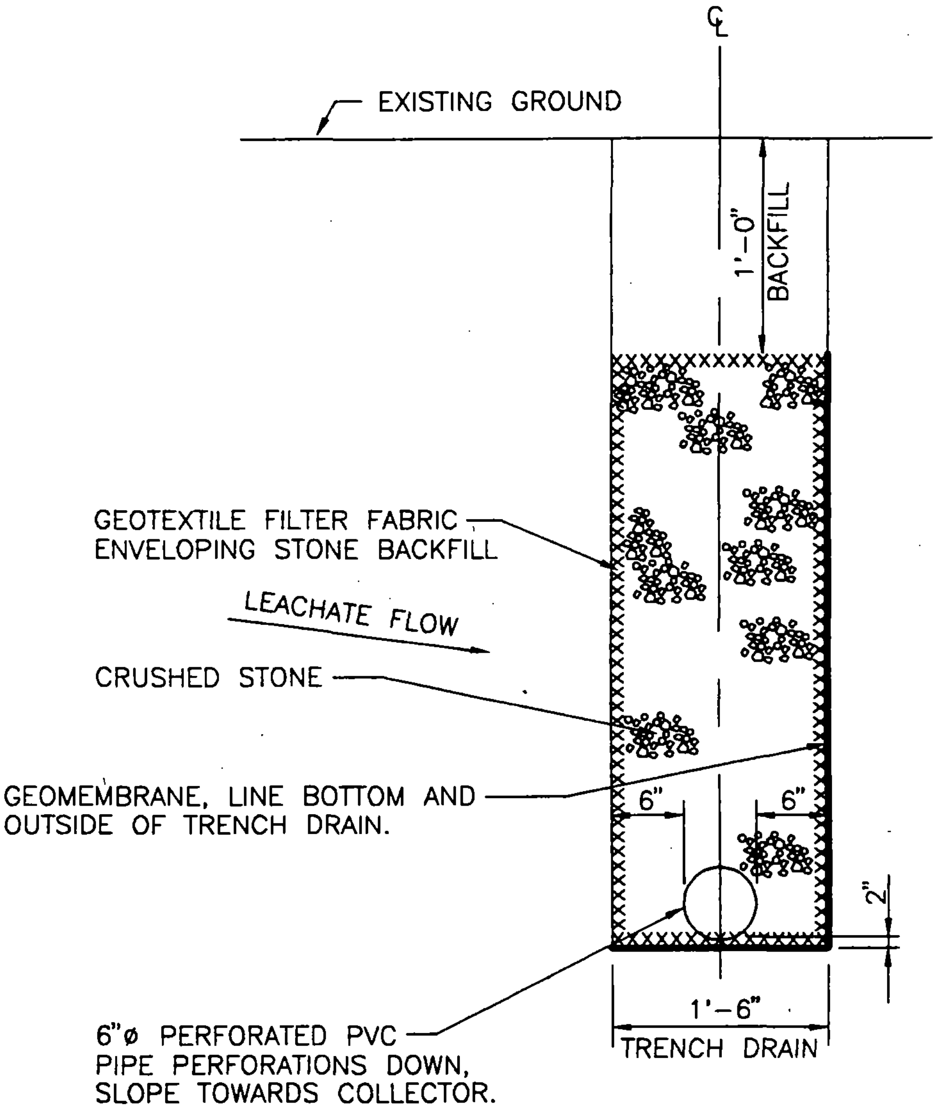
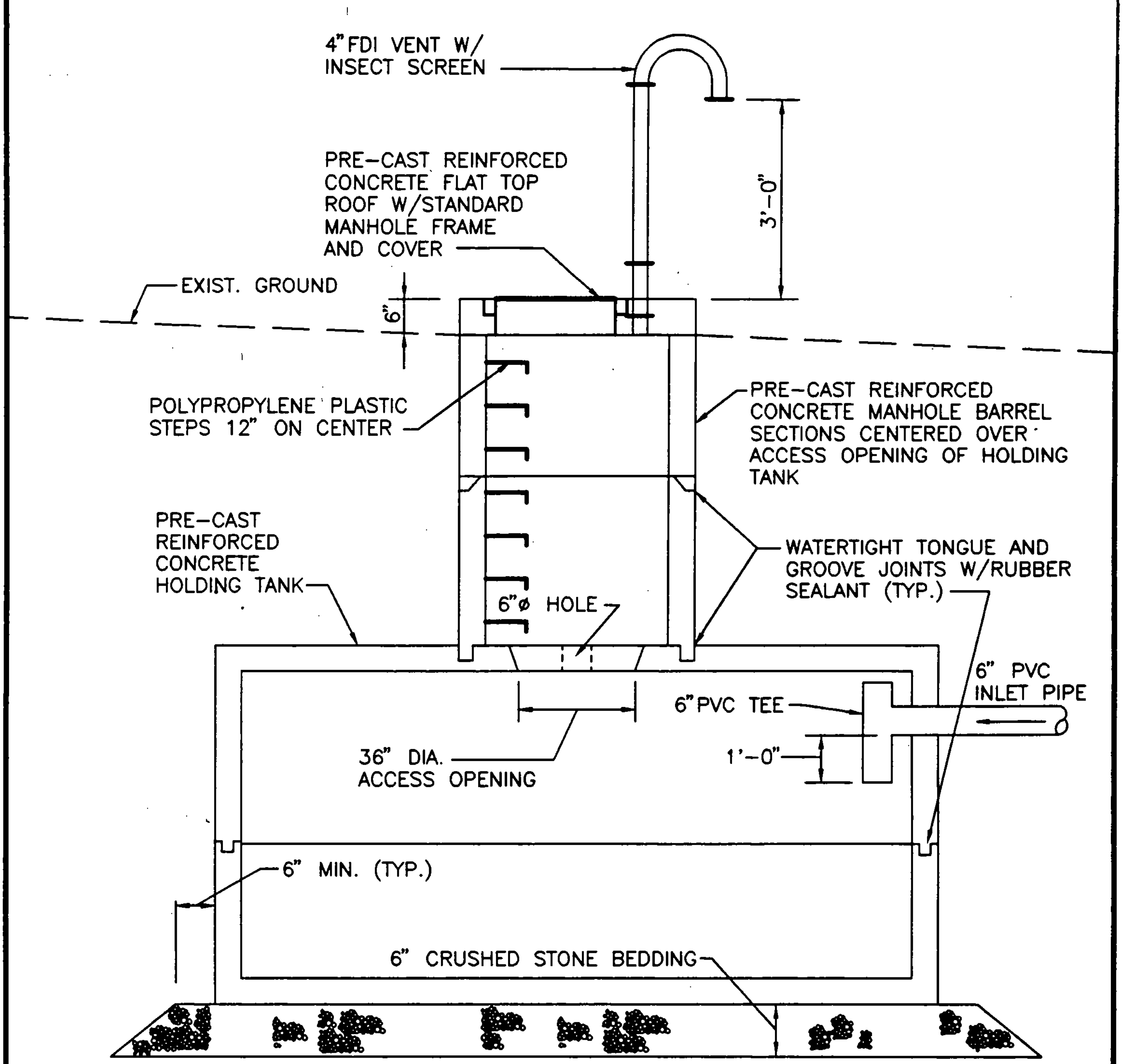


FIGURE 2
INTERCEPTOR TRENCH DRAIN AT SEEPS
SULLIVAN, MO. LANDFILL

NOT TO SCALE

Y:\6874-86\6874FIG2

ABB Environmental Services, Inc.



NOTE:
CONCRETE TANK SHOWN FOR ILLUSTRATION.
FINAL SELECTION OF CONTAINER MATERIAL TO
BE MADE DURING FINAL DESIGN.

FIGURE 3
PRECAST REINFORCED CONCRETE HOLDING TANK
SULLIVAN, MO. LANDFILL

Y:\6974-85\6974FIG3

minimum, ten days worth of anticipated average flow, plus, as a buffer, an additional five days worth of average flow. Each tank will be monitored for leachate level and contents will be disposed of offsite periodically at a rate equal to the standard size of a tanker truck, (i.e., at 5,500 gallon intervals). A turnout will be constructed from the existing access road to provide access to the tank collecting liquid from Seeps 1 through 4, while extensions to existing access roads will be constructed to provide access to tanks collecting liquids from Seeps 5, 6, and 7.

Because the seeps will be actively collected and buildup of seep liquid will no longer occur, the existing earthen berms will no longer serve a purpose and will be removed and used as fill to achieve desired grades beneath the landfill cap in the seep areas. The seven former seep areas will be included under the landfill cap.

Specific details of the proposed leachate seep remediation will be developed during the final design phase and submitted to MDNR for review.

2.5 Sinkhole Treatment During Closure

Upon review of the Draft Closure Plan, MDNR requested that more information be provided relative to treatment of the sinkhole during closure.

To increase understanding of the physical properties of the subsurface at the sinkhole and the impacts the proposed landfill cap would impose there, a test pit investigation program was performed. Eleven test pits (TP1 - TP11) were excavated in the sinkhole during the week of March 15, 1993. The purpose of the sinkhole test pits was to identify wastes that may have been disposed in the sinkhole during landfill operations, determine the location of a subsurface drain, or swallow hole, and ascertain bedrock depth. Now completed, determination of these sinkhole properties will enable the landfill closure program to proceed to the final design phase. Final design will incorporate the findings of the test pit program which are described below.

To further assess alternative approaches to sinkhole treatment during closure as well as to other aspects of cap design, twenty-nine test pits (TP 12 through TP40) were excavated in the landfill area to verify delineation of waste disposal as presented in the Site Investigation and Remedial Assessment (SIRA) Report (ABB-ES, 1992a).

As described below, results of these test pits were also used to develop the approach to addressing the sinkhole during closure.

All test pits were excavated by Signal Environmental Services with oversight provided by ABB-ES. Representatives from the MDNR were present during the test pit program. Photoionization detector readings were taken within all pits and organic vapor levels were measured at zero at all locations.

2.5.1 Test Pit Findings

Test pits TP1 through TP11 were excavated at the locations shown in Figure 4. A varying two-to-four foot thick layer of wood ash was observed in most pits, as well as an occasional empty bottle or bit of household rubbish. The observation of wood ash is consistent with verbal reports by a former landfill operations worker that the sinkhole received wood wastes during landfill disposal operations. The eleven pits ranged in depth from two to 16 feet below ground surface (bgs). Bedrock was encountered at the bottom of each pit. Figure 4 summarizes depth to rock measured in each of the pits. Figure 5 shows east-west and north-south bedrock profiles. Profile orientation is shown in Figure 4.

TP1 was excavated at the location where, during previous landfill investigations, surface water had been observed infiltrating into the sinkhole. Starting at a depth of four feet bgs in TP1, relatively competent bedrock was encountered to a depth of about three feet. Above competent bedrock (i.e., zero to four feet bgs) were varying layers of sand and clay. Below the competent bedrock was layered rock which, when exposed in the excavation, dropped from approximately six inches to a foot from its own weight, leaving a knob of competent rock above. It appears that this location is the outlet, or swallow hole, for water draining from the sinkhole. TP2 through TP11 exhibited overburden/bedrock features similar to those in TP1, with the exception that there was no apparent evidence of a swallow hole in any of the pits.

2.5.2 Delineation of Waste Area Limits

Test pits TP12 through TP40 were excavated to determine whether waste disposal occurred at their respective locations. The results allow a more accurate delineation of the landfill limits especially in relation to the general area of the sinkhole. In general, landfill limits determined from results of the test pits correlate well with the previously-understood limits derived from ABB-ES' geophysical investigation. There

SINKHOLE TEST PITS	
DEPTH TO BEDROCK	
T.P. NO.	DEPTH TO ROCK BELOW GROUND SURFACE (FEET)
1	4
2	12
3	12
4	10
5	16
6	8(NO. END) RISING TO 2(SO. END)
7	10(NO. END) RISING TO 4(SO. END)
8	10(NO. END) RISING TO 5(SO. END)
9	2
10	10(SO. END) RISING TO 4(NO. END)
11	10

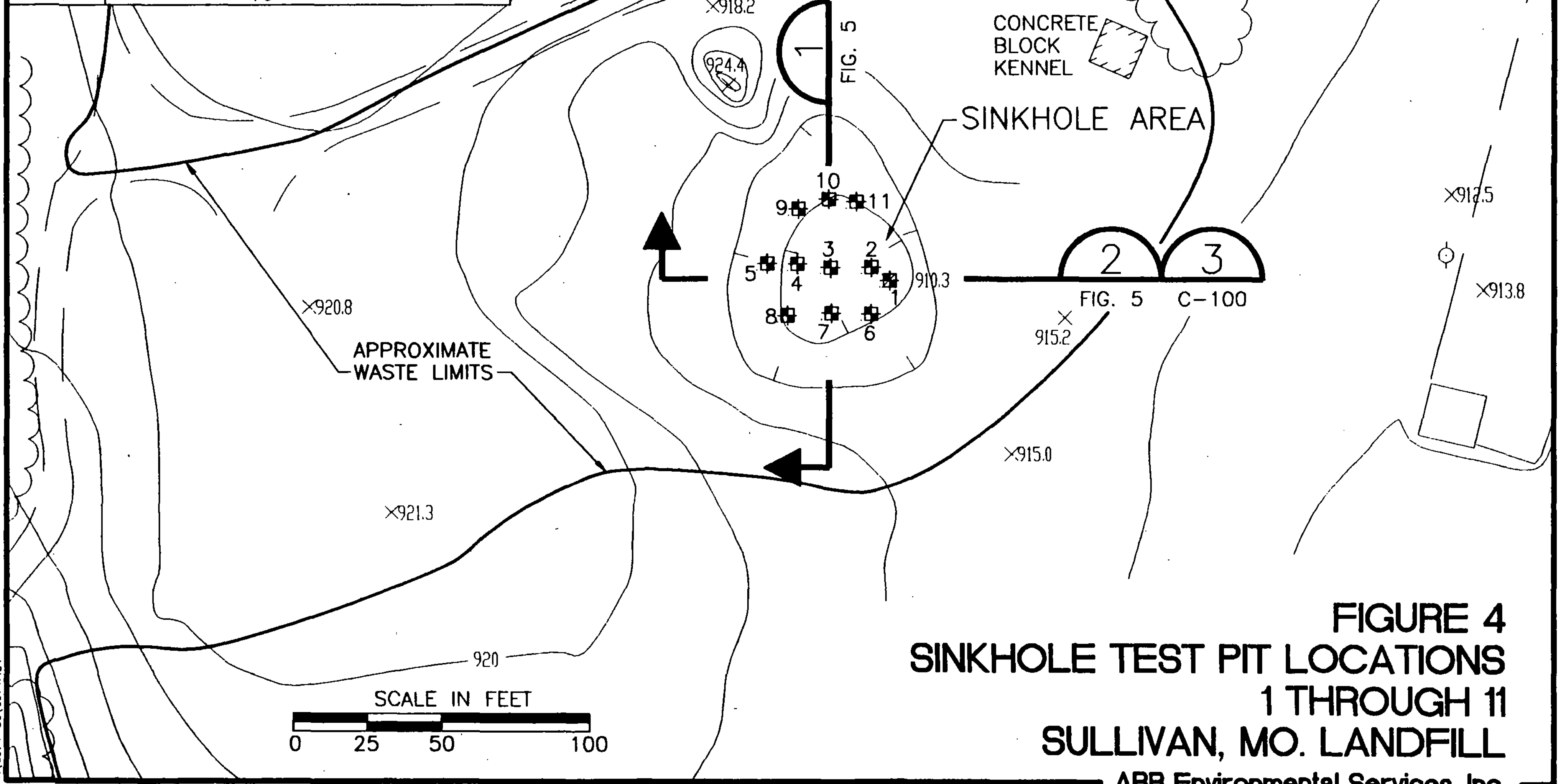


FIGURE 4
SINKHOLE TEST PIT LOCATIONS 1 THROUGH 11
SULLIVAN, MO. LANDFILL

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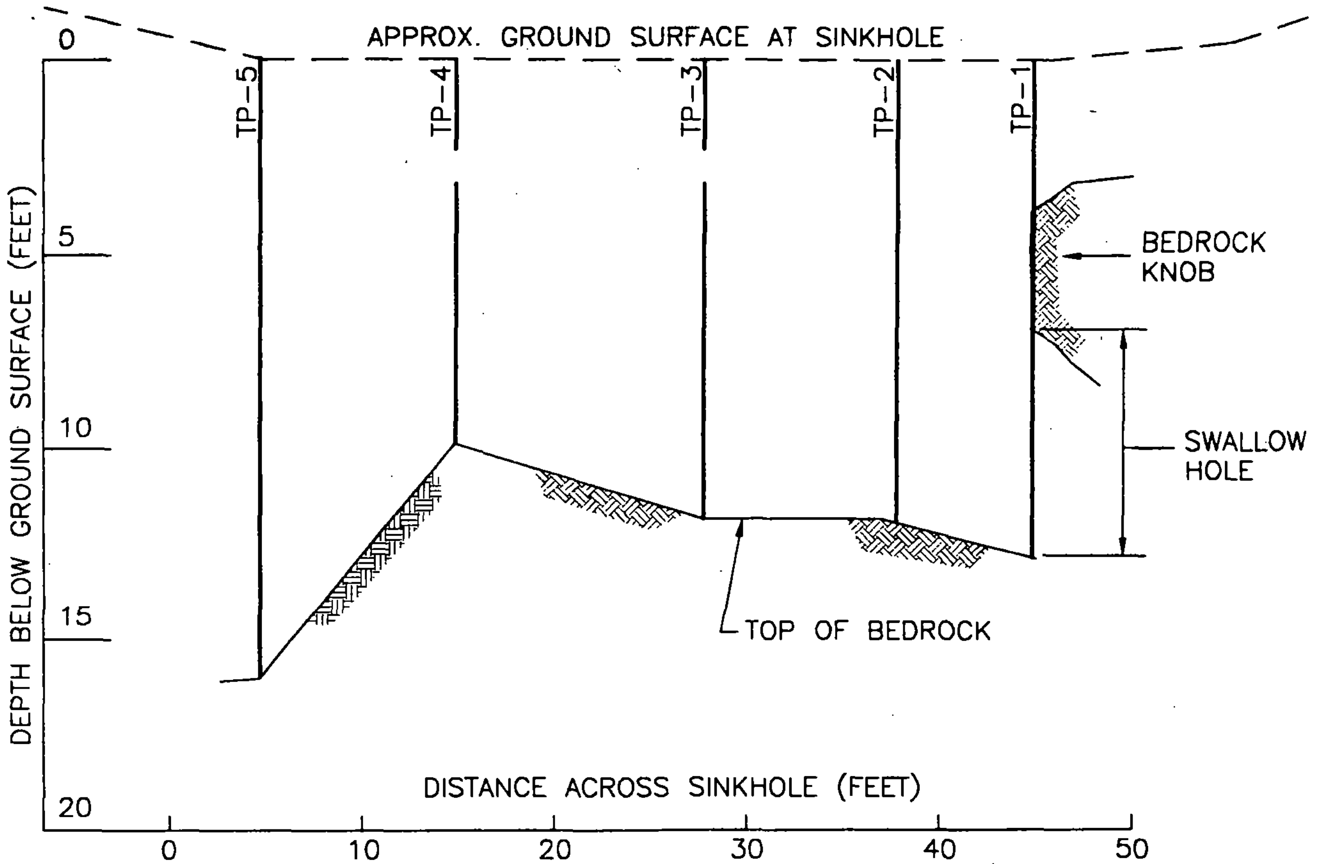
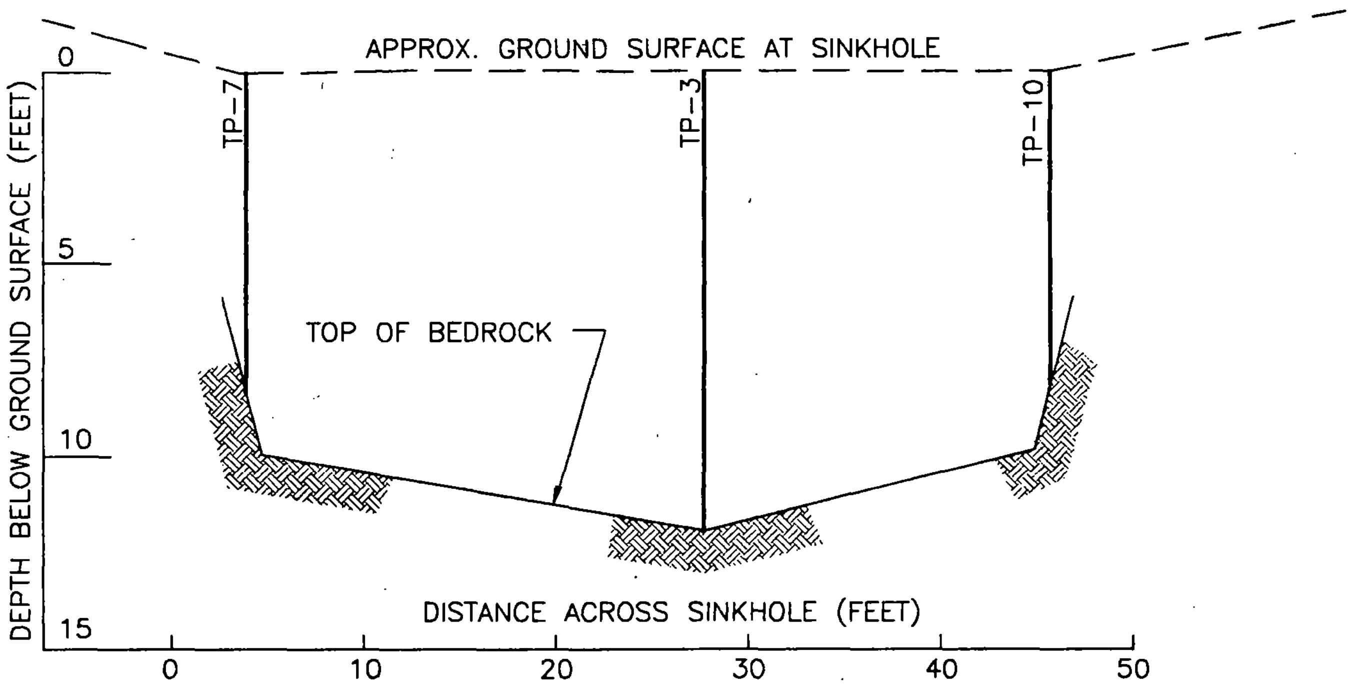


SINKHOLE EAST-WEST 2

FIG. 4



SINKHOLE NORTH-SOUTH 1

FIG. 4

FIGURE 5
SINKHOLE SECTIONS 1 AND 2
SULLIVAN, MO. LANDFILL

ABB Environmental Services, Inc.

Y:\6974-86\6974FIG5

was a single significant exception: just outside of the sinkhole, there was no evidence of waste disposal observed. Revised landfill limits in the sinkhole area based on test pit results are shown in Figure 6.

2.5.3 Stabilization of the Sinkhole Area

Using the information from the test pit program, the following conceptual design is proposed for addressing the sinkhole during landfill closure.

A two-phase capping treatment is planned for the sinkhole area. The two phases are:

1. Excavate the overburden soils over the sinkhole and the swallow hole identified during the sinkhole test pit program and construct a geosynthetic reinforcing system to stabilize the sinkhole.

2. Backfill the stabilized sinkhole and construct a cap independent of the cap on the remainder of the landfill.

A plan and conceptual profile of the proposed sinkhole treatment is shown in Appendix B.

As part of the overall landfill construction, the contractor will excavate the overburden soils at the sinkhole and swallow hole. After exposing the swallow hole, a determination will be made of the actual extent of the swallow hole and of the loose rock depicted in Appendix B. The loose rock and the bedrock knob located immediately east of the swallow hole will be removed using standard bedrock excavation techniques. A stiff mix of concrete will be placed over the swallow hole and jagged bedrock areas. The concrete will provide a plug for the rock voids that constitute the swallow hole, and a smooth base upon which to construct the synthetic reinforcing system.

The reinforcing system will likely consist of geogrid(s) and geosynthetic fabric(s) covering the swallow hole and base of the sinkhole. The system will be anchored into the overburden soils as shown in Appendix B. The type, size, and number of layers of geogrid will be selected to bridge the swallow hole and to provide protection against soil loss and settling once the overburden soils are backfilled and the cap constructed. The proposed geosynthetic reinforcing system shown in Appendix B is a conceptual depiction of the design based on conditions observed to

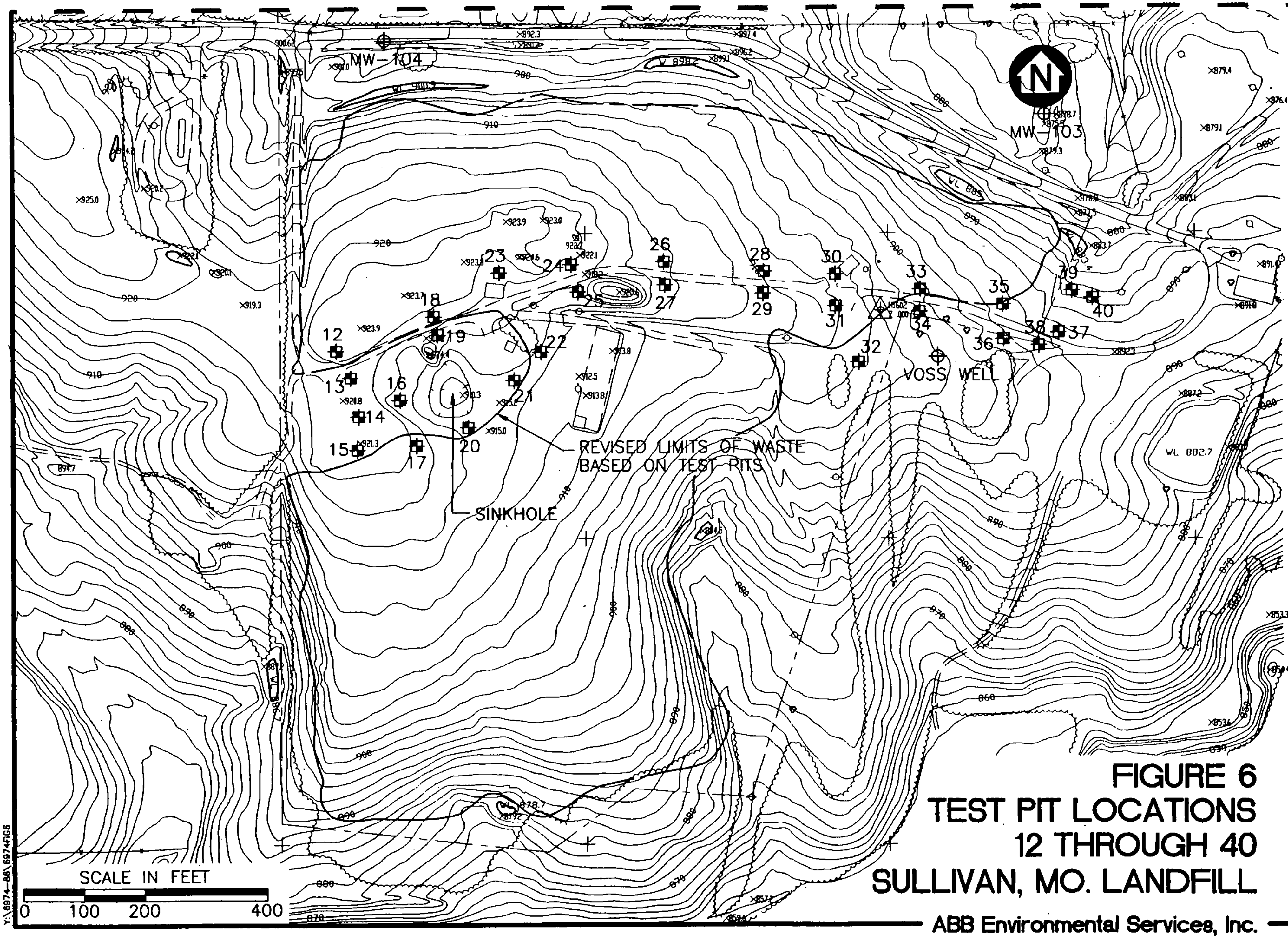


FIGURE 6
TEST PIT LOCATIONS 12 THROUGH 40
SULLIVAN, MO. LANDFILL

ABB Environmental Services, Inc.

Y:\6974-88\6974FIG6

date at the swallow hole. The number and types of geosynthetics will be selected at a later date and will be refined and field adjusted as necessary to accommodate conditions observed during future excavations. The proposed reinforcing system has been reviewed and approved by [redacted] a subcontractor to ABB-ES.

Ex. 6

[redacted] has more than 25 years of experience in hydrogeology, and specializes in Karst hydrogeology. He served for nine years as the Director of the Florida Sinkhole Research Institute prior to entering private practice. [redacted] will continue to offer consulting services to ABB-ES relative to cap design at the Sullivan Landfill sinkhole through the project's construction phase.

The cap over the sinkhole will be constructed as shown in Appendix B. Precipitation runoff that flows toward the sinkhole from the landfill will be collected by a drainage ditch and drained before reaching the sinkhole area. A continuous lining system over the sinkhole will prevent infiltration into the sinkhole. The advantages of a landfill cap independent from the remainder of the landfill are: a shallower depth of cover over the sinkhole is achieved; and in the unlikely event that significant sinkhole settlement should occur, remediation of this portion of the cap can be performed without impact to the surrounding landfill.

2.6 Post-Closure Groundwater Monitoring

MDNR requested that the post-closure groundwater monitoring program proposed in the Closure Plan be revised to be responsive to program requirements defined in the State of Missouri Solid Waste Regulations (10 CSR 80-2.030). The following revised program is proposed.

A program is prepared that will allow for evaluation, on a periodic basis, of the concentrations and extent of chemicals in the groundwater system in the vicinity of the landfill. Groundwater sampling locations will include: upgradient monitoring well (MW)-101 and downgradient wells MW-102A, MW-102B, MW-103, installed during the landfill site investigation phase, and the so-called Voss well. As discussed in the SIRA Report, these wells adequately monitor groundwater quality associated with the landfill site (ABB-ES, 1992a).

The proposed post-closure groundwater monitoring program includes twice annual collection and analysis of groundwater samples (i.e., spring and summer) for two years following cover construction, and annual collection and analysis each year during the summer for the remainder of the five-year monitoring period. The monitoring program will be reviewed at the conclusion of the five-year monitoring period and an evaluation of the value of continued monitoring determined. Although this monitoring program differs in some respects with MDNR Solid Waste Guidance, specifically with regard to frequency and duration, it is consistent with U.S. Environmental Protection Agency (USEPA) guidance for groundwater quality monitoring in karst terrains. Current USEPA guidance regarding groundwater monitoring in karst terrains recommends that sampling events correspond to both low-flow (winter) and high-flow (spring) conditions, and is the basis for the proposed sampling frequency over the first two-year period (McCann et al., 1991) .

Consistent with groundwater samples collected and analyzed during site investigation, post-closure groundwater samples will be analyzed for volatile organic compounds (VOCs) using USEPA Methods 8010/8020. A non-linear regression analysis of groundwater data will be conducted to evaluate site data. Water quality data reports will be submitted following each sample round and will include an analysis of analytical data, water level data, and an evaluation of site conditions. Water quality data collected at this proposed frequency, over a five-year monitoring period, will allow for an adequate evaluation of any changes in groundwater quality following landfill closure.

As a result of MDNR comments in their August 16, 1993 letter, the groundwater monitoring frequency as well as the monitoring locations and analytes were modified. Both the MDNR August 16, 1993 letter and ABB-ES' September 24, 1993 letter containing the modifications are included as Appendix C.

2.7 Financial Assurance

MDNR requested that financial assurance be provided relative to landfill closure costs. The assurance package, currently being prepared, will be transmitted directly to MDNR upon completion.

2.8 Settlement Markers

MDNR requested that more information be provided relative to landfill cap settlement monitoring during the post-closure monitoring and maintenance period.

ABB-ES believes that settlement of wastes after capping is not a significant concern at the Sullivan Landfill for the following reasons:

1. As described in Subsection 2.5, the sinkhole will be stabilized to preclude post- closure settlement.

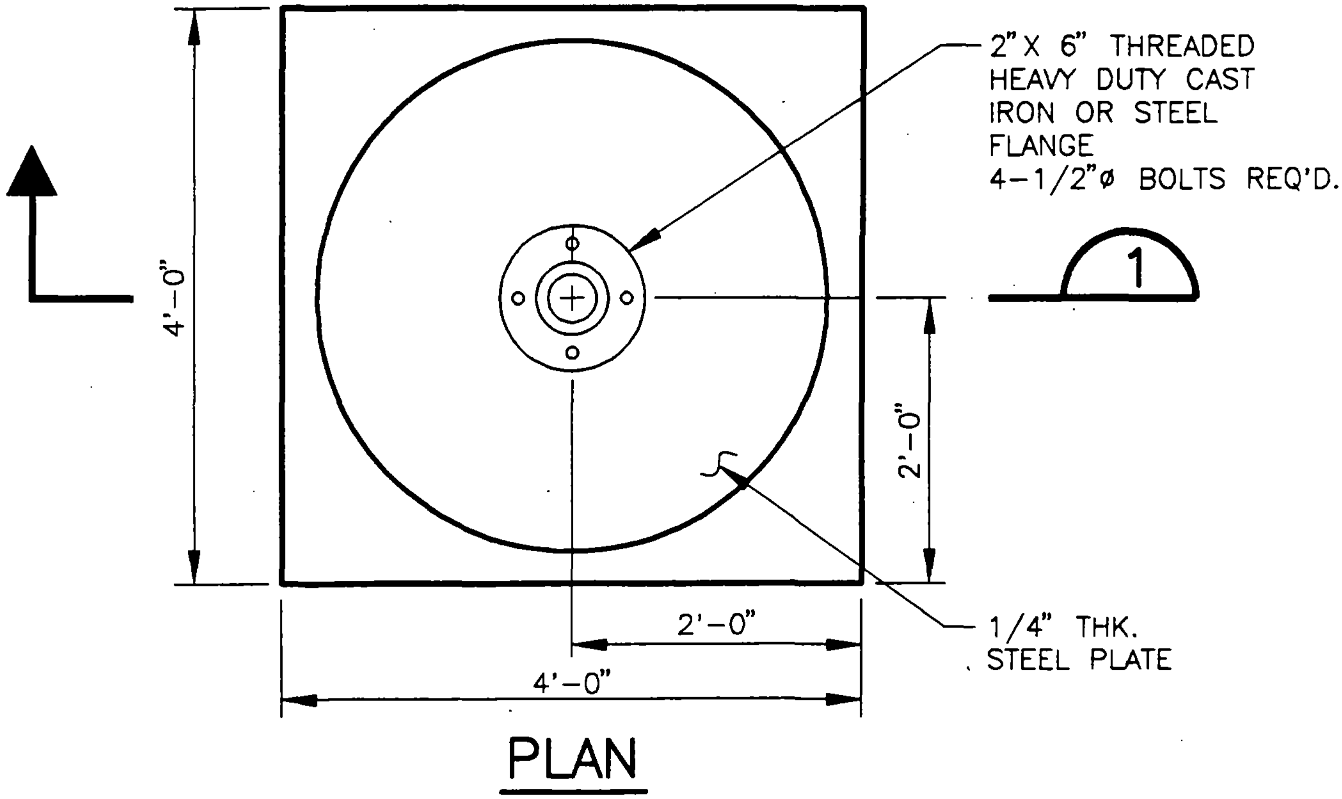
2. Reported waste depth at the landfill is relatively shallow, on the order of 20 feet or less. The waste is likely to be already compressed by its own weight and by the weight of heavy equipment present at the landfill during disposal operations.

3. The age of the waste in the landfill (20+ years) suggests that much of the settlement due to decomposition and biodegradation may have already occurred.

4. The thickness of the proposed cap (average 5.5 feet including subgrade soil) consists mostly of only the cap thickness itself. Average subgrade soil thickness, approximately 12 inches, is relatively small.

ABB-ES recommended placing markers to monitor potential cap settlement at three areas on the landfill: (1) the ravine disposal area in the landfill's southern portion; (2) the trench landfill area in the landfill's northern portion; and (3) at the sinkhole. The first and second locations represent areas where two distinct landfilling methods were employed during landfill operations (i.e., dump and bury in the ravine area and excavate, place, and cover in the trench area). The third area would monitor potential settlement at the sinkhole area following the stabilization and capping treatment described in Subsection 2.5. As a result of an MDNR comment expressed in their August 16, 1993 letter, five additional settlement markers were added to the program, and one was deleted. Both the MDNR August 16, 1993 letter and ABB-ES' September 24, 1993 response letter including a figure showing the seven monitoring locations are included as Appendix C.

Details of the proposed settlement markers and placement locations are shown in Figure 7 and 8, respectively. Settlement monitoring will be performed quarterly during the first year of post closure, semiannually for the following two years, and annually through the fifth post-construction year. Based on results to that point, recommendations will be made for frequency of future continued monitoring, if required.



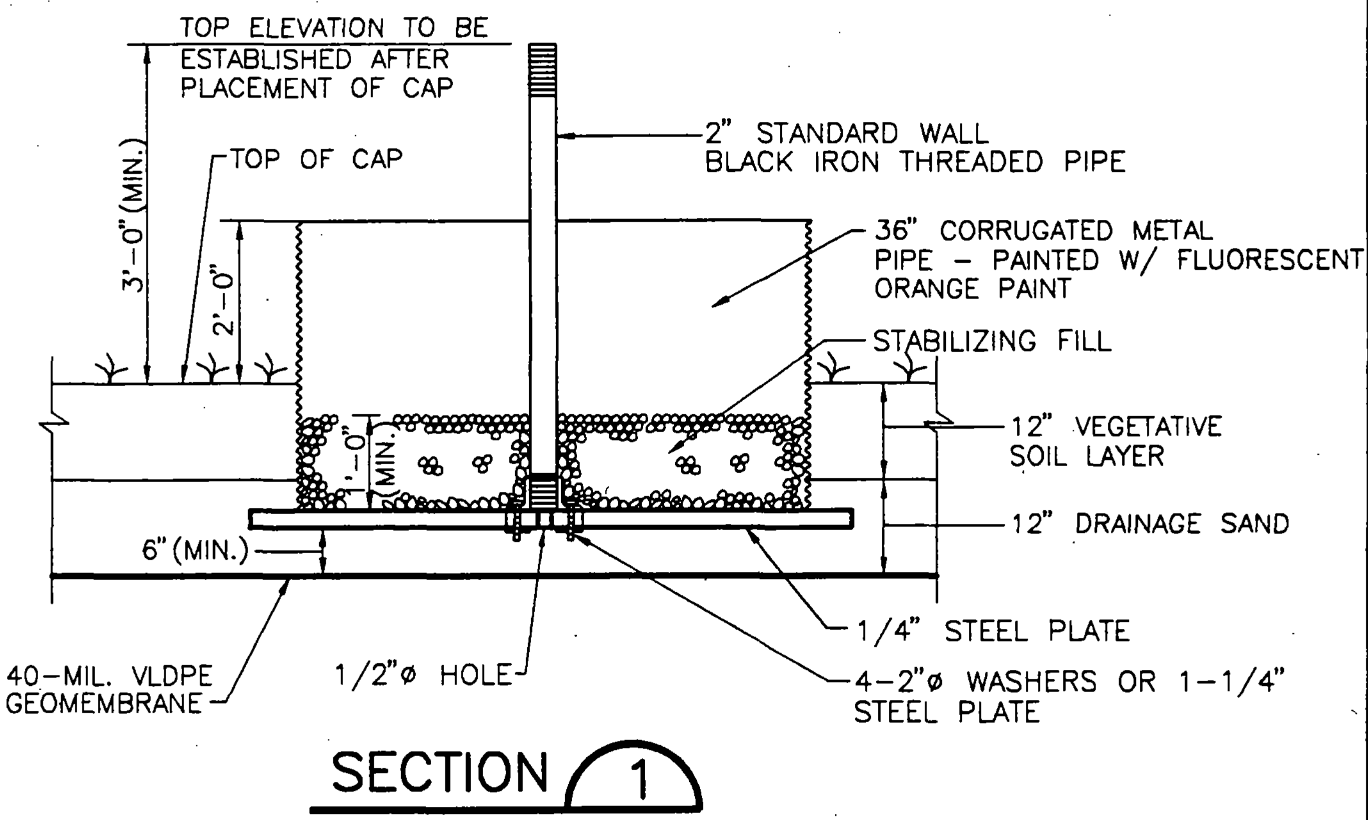


FIGURE 7
SETTLEMENT PLATFORM
SULLIVAN, MO. LANDFILL

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Y:\6974-86\6974FIG7

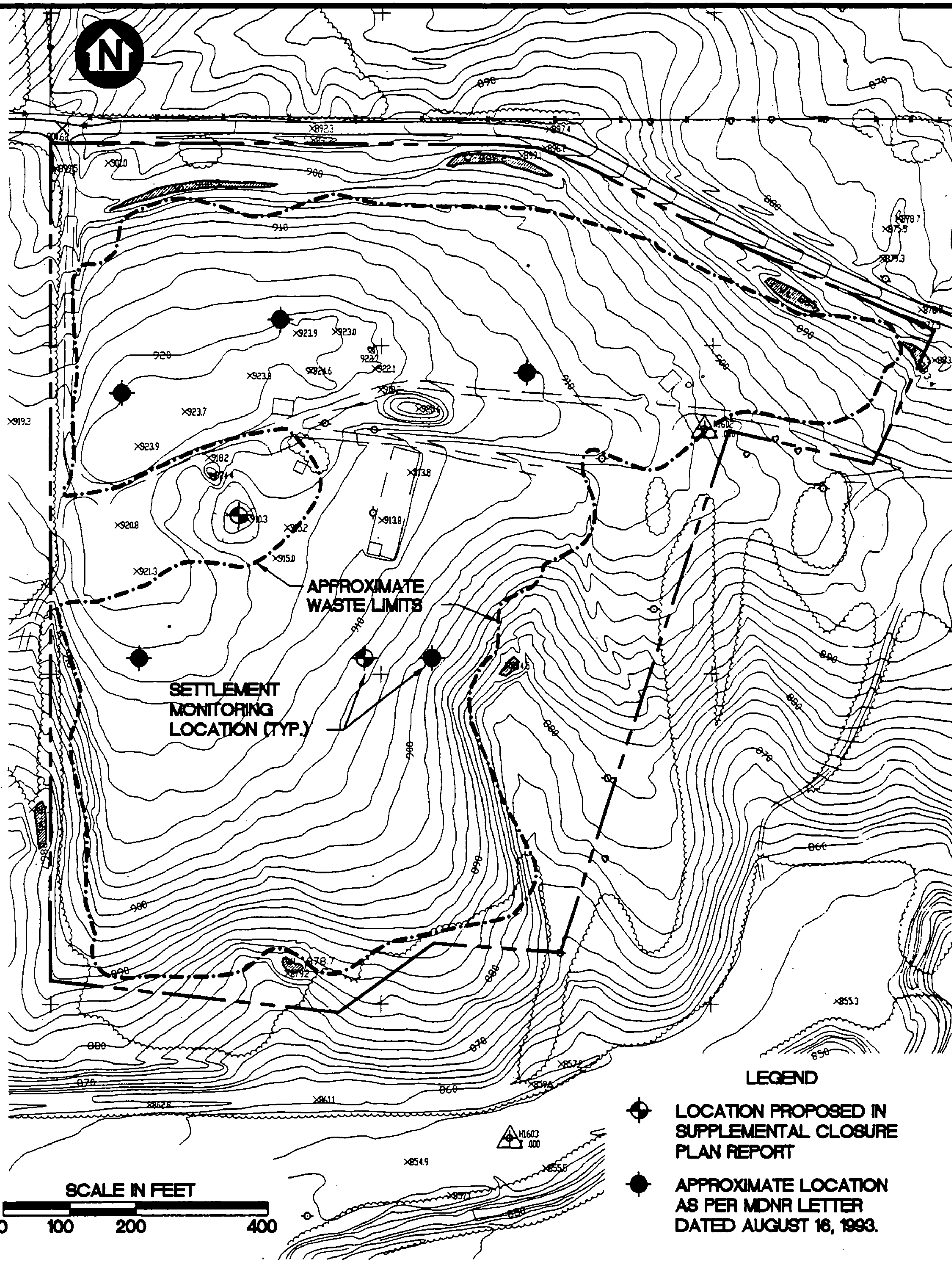


FIGURE 8
SETTLEMENT MONITORING LOCATIONS
SULLIVAN, MO. LANDFILL

ABB Environmental Services, Inc.

H:\6974-86\6974FIG9.DWG

3.0 RESPONSE TO MDNR COMMENTS OF MAY 1993

During a telephone call to ABB-ES on May 27, 1993, MDNR requested that ABB-ES calculate stresses on 40-mil VLDPE and evaluate the ability of the geomembrane to resist the stresses for three scenarios:

1. no earth cover on the geomembrane;
2. earth cover using an "infinite slope analysis", and;
3. earth cover using a "finite slope analysis".

Calculations addressing the ability of the proposed 40-mil geomembrane to withstand the stresses associated with the three scenarios are attached in Appendix D. For comparison, literature values for VLDPE are presented for two vendors, NSC and Poly-Flex. For the first scenario, the computations derive the factor of safety (F.S.) relative to the manufacturer's standard roll length placed on a 3:1 slope with no earth cover. Factors of safety of 1.5 - 2.0 are typically the present state-of-practice in the U.S. for design of polyethylene geomembranes (Berg and Boneparte, 1993). Using the manufactured roll lengths of 1,670 feet for NSC and 600 feet for Poly-Flex, an F.S. range of 17 to 44 is provided by the evaluated vendor products.

For the second scenario, the proposed Sullivan Landfill cap components were used to evaluate the stress imposed by 24 inches of soil over a length of 500 feet at a slope of 7 percent. These values are considered typical for a long run of geomembrane at the average slope anticipated for the Sullivan Landfill cap. The resulting computations show an F.S. range of 3.3 to 4.3 for the evaluated vendor products.

Computations for the third scenario incorporate the cap treatment likely at the perimeter of the proposed landfill cap, i.e., a 4:1 slope over a slope length of 25 feet. This scenario represents a typical proposed application at the Sullivan Landfill perimeter where the cap is tapered to match existing grade. The resulting computations present an F.S. range of 2.1 to 2.4 for the evaluated vendor products. Computations for the third scenario should be considered preliminary and are likely to change during final design. At that time, a slope stability evaluation based on further refinements to the cap design may require changes to the assumptions contained in this scenario.

Based on these calculations, 40 mil VLDPE meets all necessary safety factors for its anticipated use at the Sullivan Landfill.

4.0 CONCLUSION

The submittal of this Closure Plan Supplemental Report completes ABB-ES' responses to all MDNR comments. ABB-ES looks forward to written approval of the Closure Plan by MDNR and subsequent implementation of the closure elements. Response to Subsection 2.7, Financial Assurance, will be provided directly by the Sullivan Landfill PRP Committee.

bgs	below ground surface
FS	Factor of Safety
MDNR	Missouri Department of Natural Resources
USSCs	U.S. Soil Conservation Service
USEPA	U.S. Environmental Protection Agency
VLDPE	Very Low Density Polyethylene
VOC	volatile organic compound

ABB Environmental Services, Inc., (ABB-ES), 1992a. Sullivan Landfill Site Investigation and Remedial Assessment Report; September 1992.

ABB Environmental Services, Inc., (ABB-ES), 1992b. Sullivan Landfill Closure Plan; November 1992.

ABB Environmental Services, Inc., (ABB-ES), 1993. Sullivan Landfill Site Investigation and Remedial Assessment Supplemental Report; July, 1993.

Berg, R., and R. Bonaparte, 1993. "Long-term Allowable Tensile Stresses for Polyethylene Geomembranes"; *Geotextiles and Geomembranes*; No. 12; pp. 287-306.

McCann, M.R. and J.F. Quinlan, 1991. "Development of an ASTM Standard Guide for the Design of Groundwater Monitoring Systems in Karst and fractured Rock Terrains"; *Proceedings of the National Groundwater Association's Third Conference on Hydrogeology, Monitoring, and Management of Groundwater in Karst Terrains*; December, 1991.

LEACHATE SEEP RATE CALCULATIONS

PROJECT	COMP. BY	JOB NO.
EVALUATION OF TIME REQUIRED TO DRY UP SULLIVAN LANDFILL SEEPS	A.H	6974-Tb
	CHK. BY	DATE 7-1-93

The Help Model was run to evaluate the effect a hydraulic barrier will have on leachate generation. Model runs indicate that lateral drainage, or percolation through a permeable unit, may result in 20 to 30% of infiltrating precipitation being directed to seep areas. The installation of a 10^{-7} cm/sec barrier layer would eliminate flow to this drainage and zone and eliminate the driving force of the seep areas.

The Help Model indicates (as is expected) that no flow would recharge this system following cap installation as indicated on the attached model output. The Help Model indicates that continued recharge of the seeps is a function of the flow rate into the seeps and volume of water remaining within the landfill following cap installation.

Calculations were made to evaluate the amount of water remaining in the unsaturated zone post-cap installation. Calculations were then made to evaluate the total flow [Q] into the seep areas. These calculations provide a range of estimates for the time required for the seeps to effectively drain the volume of water remaining within the landfill following the initial pumping of the seep areas.

<u>Assumptions in this Analysis</u>

1. The only mechanism recharging the seeps is direct infiltration on them and flow of infiltrating precipitation along residual sandstone layers.

2. The hydraulic gradient of the unsaturated flow is primarily a function of the slope of the bedrock.

3. It is assumed that a total of 10 acres (435600 ft^3) recharge the seep areas, based on a review of drainage and topography at the site.

4. Flow along the bedrock directs precipitation to the seeps. No infiltration of precipitation through the sandstone occurs (very conservative).

5. Seeps, on average, are 200 feet long and 10 feet deep.

6. It is assumed that the slope of the unsaturated flow hydraulic gradient is consistent with the seep areas.

7. Given the potential presence of clay within the soils overlaying the rock, a porosity of 40% was assumed.

8. It is assumed that the water layer on top of the residual sandstone ranges from 0.1 to 0.2 feet in thickness.

PROJECT	COMP. BY	JOB NO.
EVALUATION OF TIME REQUIRED TO DRY UP SULLIVAN LANDFILL SEEPS	PJH.	6974-86
	CHK. BY	DATE 7-1-93

$Q = kiA$

Q = flow Rate

k = Range from 9×10^{-5} cm/s (.28 ft/d) to 3×10^{-4} cm/s (1.4 ft/d)

i = .03 to .02 ft/ft

A = 14,000 ft^3

$Q = (1.4)(.03)(14{,}000) = 588\ ft^3/d = 3\ gpm = 4320\ gpd$

$Q = (.28)(.02)(14{,}000) = 78\ ft^3/d = .4\ gpm = 588\ gpd$

Volume of water left in landfill

0.1 ft of water on top of SandStone

10 acres = 43,560 ft^3 = 326,700 gallons

n = 40% = 130,680 gallons = $V_{landfill}$

0.2 ft of water in landfill

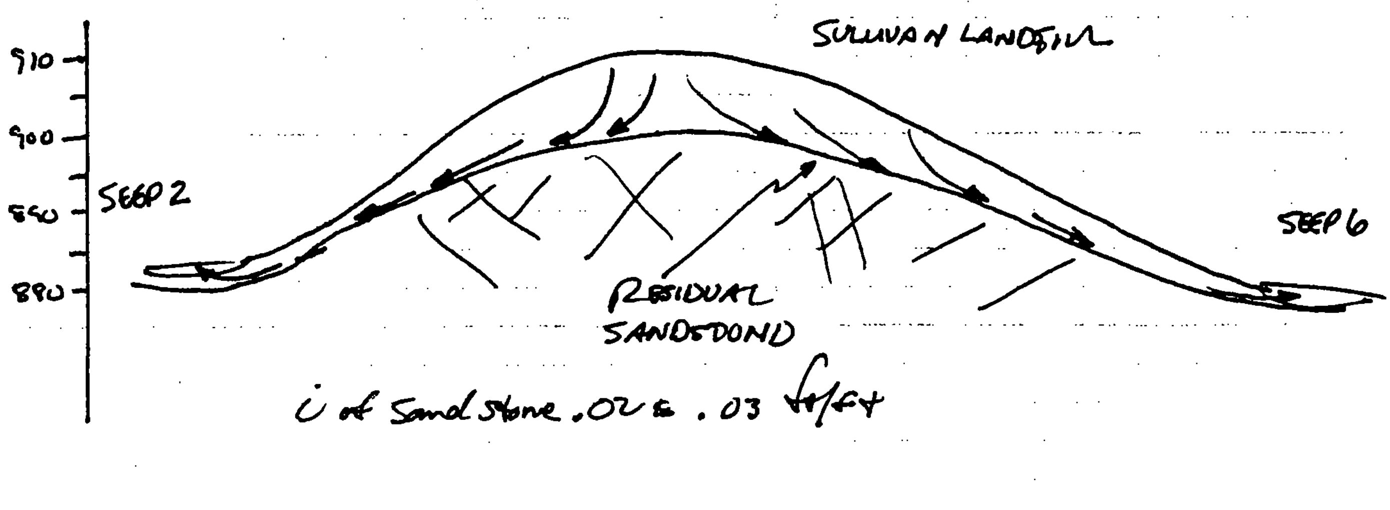
261,000 gallons = $V_{landfill}$

Time to drain this volume = once seeps are pumped dry =

30 to 222 days [POST-CAP]

Time to drain the larger volume 60 to 444 days

Based on this analysis, which is based on the assumptions listed above, the volume of water remaining within the landfill - post-cap - may range from 130,000 to 261,000 gallons. The current seep volumes are estimated at approximately 200,000 gallons which correspond reasonably well with the calculated volume. The are expected to "dry-up" with a 1 to 14 month period. The range in time estimates is largely based on hydraulic conductivity, gradients, and actual seepage flow rates into the seeps.



"HELP" MODEL

STD. DEVIATIONS 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000
0.0000 0.0000 0.0000 0.0000 0.0000 0.0000

LATERAL DRAINAGE FROM LAYER 5

TOTALS 0.0000 0.0000 0.0000 0.0000 0.0000 0.0009
0.0000 0.0000 0.0000 0.0000 0.0000 0.0000

STD. DEVIATIONS 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000
0.0000 0.0000 0.0000 0.0000 0.0000 0.0000

PERCOLATION FROM LAYER 6

TOTALS 1.1045 1.6808 2.0669 0.6954 0.9448 4.7929
0.6294 0.2797 1.1428 0.3631 0.3364 0.3688

STD. DEVIATIONS 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000
0.0000 0.0000 0.0000 0.0000 0.0000 0.0000

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AVERAGE ANNUAL TOTALS & (STD. DEVIATIONS) FOR YEARS 74 THROUGH 74

	(INCHES)		(CU. FT.)	PERCENT
PRECIPITATION	43.93	(0.000)	2929.	100.00
RUNOFF	0.002	(0.000)	0.	0.00
EVAPOTRANSPIRATION	29.521	(0.000)	1968.	67.20
LATERAL DRAINAGE FROM LAYER 2	0.0015	(0.0000)	0.	0.00
PERCOLATION FROM LAYER 3	14.4060	(0.0000)	960.	32.79
LATERAL DRAINAGE FROM LAYER 5	0.0010	(0.0000)	0.	0.00
PERCOLATION FROM LAYER 6	14.4052	(0.0000)	960.	32.79
CHANGE IN WATER STORAGE	0.000	(0.000)	0.	0.00

FLOW THROUGH LAYER 6
[SIMULATES PERMEABLE
LAYER ABOVE SANDSTONE]
⇒ NO CAP ⇐

****

****

PEAK DAILY VALUES FOR YEARS 74 THROUGH 74

	(INCHES)	(CU. FT.)
PRECIPITATION	2.98	198.7
RUNOFF	0.002	0.1
LATERAL DRAINAGE FROM LAYER 2	0.0005	0.0
PERCOLATION FROM LAYER 3	1.8359	122.4

"HELP" MODEL

STD. DEVIATIONS 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000
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LATERAL DRAINAGE FROM LAYER 5

TOTALS 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000
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PERCOLATION FROM LAYER 6

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STD. DEVIATIONS 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000
0.0000 0.0000 0.0000 0.0000 0.0000 0.0000

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AVERAGE ANNUAL TOTALS & (STD. DEVIATIONS) FOR YEARS 74 THROUGH 74

	(INCHES)		(CU. FT.)	PERCENT
PRECIPITATION	43.93	(0.000)	2929.	100.00
RUNOFF	6.644	(0.000)	443.	15.12
EVAPOTRANSPIRATION	34.999	(0.000)	2333.	79.67
LATERAL DRAINAGE FROM LAYER 2	1.6977	(0.0000)	113.	3.86
PERCOLATION FROM LAYER 3	0.5901	(0.0000)	39.	1.34
LATERAL DRAINAGE FROM LAYER 5	0.0000	(0.0000)	0.	0.00
PERCOLATION FROM LAYER 6	0.0000	(0.0000)	0.	0.00
CHANGE IN WATER STORAGE	0.589	(0.000)	39.	1.34

FLOW THROUGH LAYER 6
[SIMULATES PERMEABLE LAYER
ABOVE SANDSTONE]
=> WITH CAP <=

****

****

PEAK DAILY VALUES FOR YEARS 74 THROUGH 74

	(INCHES)	(CU. FT.)
PRECIPITATION	2.98	198.7
RUNOFF	1.857	123.8
LATERAL DRAINAGE FROM LAYER 2	0.0088	0.6

SINKHOLE PLAN, SECTIONS, AND DETAILS

APPENDIX C

.UGUST 16, 1993 COMMENTS LETTER
:PTEMBER 24, 1993 RESPONSE LETTER

B Environmental Services, Inc.

6974-87

AFT

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DRAFT

Sample containers for metals analyses were filled directly from the pump discharge. Containers for volatile organic analyses were filled with a bailer after the other sample parameters were collected.

Samples 93-1675, 93-1676, 93-1677, and 93-1678 from monitoring wells MW#103, MW#102A, MW#105, and MW#102B, respectively, were collected and split with ESP. A duplicate sample and a trip blank sample were also collected. (See Appendix A for sampling locations.)

Each sample was given a numbered tag and the corresponding number was recorded on a chain-of-custody form. Samples were analyzed for volatile organics and total metals: Pb, Ba, Cd, Hg, As, Se, Ag, and Cr. Sample 93-1675 from MW#103 was also analyzed for dissolved metals (same analytes as total metals listed above). All samples were analyzed at the state's environmental laboratory within the Environmental Services Program in Jefferson City. Laboratory procedures were followed according to the requirements and standard operating procedures of the Quality Assurance Project Plan for Fiscal Year 1993.

OBSERVATIONS

Water from all monitoring wells became less turbid during redevelopment. Monitoring wells MW#102A and MW#103 became less turbid toward the end of the redevelopment process. MW#102B and MW#105 cleared up earlier during the redevelopment process and, therefore, less volume was purged from these wells. The sample from MW#103 had a turbidity reading of 183.5 nephelometric turbidity units (NTU), as determined by Mimi Garstang using a DGLS turbidity meter. MW#102A and MW#102B had a turbidity of 35 and 28 NTU, respectively, as measured by ABB. Turbidity was not measured from MW#105.

Sample 93-1675 from MW#103 appeared slightly turbid to turbid. The sample was less turbid in the portion collected by pump than the portion collected by bailer. Samples 93-1676, 93-1677, and 93-1678 collected from MW#102A, MW#105, and MW#102B, respectively, appeared milky to slightly milky. Samples 93-1677 and 93-1678 appeared much less turbid than the other two samples.

Snow had fallen the week preceding sampling. February 11, 1993, was rainy, compounding already muddy conditions at the site.

RESULTS

See Appendix B for sample results.

ASEA BROWN BOVERI

CM099311.ltr

September 24, 1993

Mr. Steven W. Sturgess, Chief
Project Management Unit
Missouri Department of Natural Resources
P.O. Box 176
Jefferson City, MO 65102-0176

Dear Mr. Sturgess:

Subject: Resolution of Outstanding Issues
Sullivan Landfill Closure

Your letter dated August 16, 1993 acknowledged that there were four outstanding issues to be resolved before Missouri Department of Natural Resources (MDNR) could complete approval of the Site Investigation and Remedial Alternatives (SIRA) Study and the Closure Plan for the Sullivan Landfill closure. The Sullivan Landfill PRP Group agrees to modify the proposed Closure Plan approach to fully address the four issues identified in your letter. On this basis we request your formal approval of the SIRA Investigation Report and the Closure Plan so that we may proceed expeditiously with the closure design and planning for the construction activities.

The following four modifications are made to the proposed Closure Plan:

1. Groundwater monitoring will include inorganic metals analysis for chromium, lead, and barium. Both dissolved and total metals analyses will be conducted.

2. Quarterly monitoring will be conducted for the first two years. Depending on sample results, periodicity of sampling may be reduced, subject to MDNR approval. A five year data review will be conducted and recommendations for monitoring into future years will be made at that time.

3. Monitoring during the five years following construction will be conducted at MW-101, MW-102A and B, MW-103, MW-105, the Voss well, and B-201.

ABB Environmental Services, Inc.

110 Free Street
P.O. Box 7050
Portland, Maine 04112-7050

Telephone (207) 775-5400

Fax (207) 772-4762

ASEA BROWN BOVERI

4. Additional settlement markers will be added to the landfill settlement monitoring program as follows: Settlement markers will be installed at the top of the slope on the west side; on the east side and the west side of the top of the slope at the south end of the "ravine fill" area; and, two at the top of the slope along the north perimeter of the trench fill area. As indicated in your letter, our initially proposed northernmost marker is substituted with these. General locations for proposed settlement markers are shown in the attached figure. Settlement surveys will be run quarterly during the first year, semiannually for the following two years, and annually through the fifth post-construction year. Based on results to that point, recommendations will be made for frequency of future continued monitoring, if required.

As you indicated in your August 16, 1993 letter, MDNR's Division of Geology and Land Survey (DGLS) and Environmental Services Program have raised several additional issues that MDNR would like to resolve but that will not delay the approval process. As a next step to resolve them, we will provide MDNR with a response that addresses each of the issues. This will be sent to you by October 15, 1993.

Again, thank you for your guidance and prompt action. With your approval in hand we can move forward expeditiously to complete the design process to meet the goal of landfill cap construction during 1994.

Sincerely,

ABB ENVIRONMENTAL SERVICES, INC.

Andrew J. McCusker

Andrew J. McCusker
Project Manager

cc: C. Bingham, TRW
J. Butz, City of Sullivan

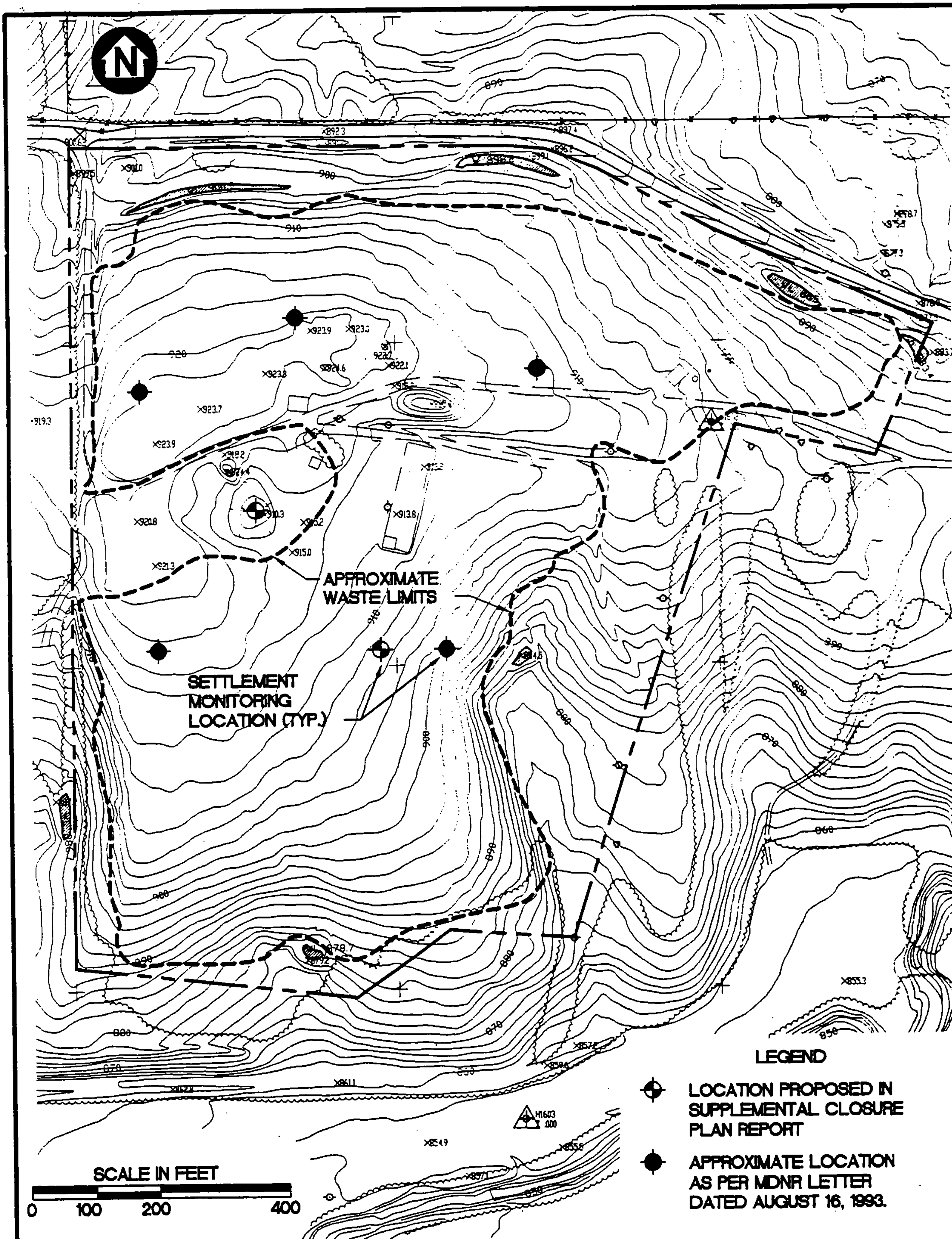


FIGURE 1
SETTLEMENT MONITORING LOCATIONS
SULLIVAN, MO. LANDFILL

ABB Environmental Services, Inc.

STRESS EVALUATION CALCULATIONS

ABB ENVIRONMENTAL SERVICES, INC.

APPENDIX D

STRESS EVALUATION CALCULATIONS

ENGINEERING CALCULATIONS COVER SHEET

PROJECT: TRW - SULLIVAN LANDFILL CLIENT: TRW

CALCULATION IDENTIFICATION			
PROJECT NO.	CALCULATION NO.	WORK PACKAGE	DISCIPLINE
06974-87	1	1	GEOTECH

PREPARED BY	DATE	REVIEWED BY	DATE	APPROVED BY	DATE	SUPERSEDES CALC. NO.
K [illegible]	6/25/1993	LYLE TEACH	6/28			—

CALCULATION TITLE	INPUT CONFIRMED	
	YES	NO
EVALUATION OF STRESS IMPOSED ON GEOMEMBRANE COVER	✓	

REVISIONS								
NO.	PREPARED BY	DATE	REVIEWED BY	DATE	APPROVED BY	DATE	INPUT CONFIRMED	
							YES	NO

SUPERSEDED BY CALCULATION NO.: — DATED: —

REASON SUPERSEDED: —

PROJECT
SULLIVAN LANDFILL, MO
TRW

COMP. BY KHL
CHK. BY LT

JOB NO. 6974-87
DATE 6/25/93

AS PART OF COMMENTS RECEIVED FROM MDNR RESPOND TO THE FOLLOWING QUESTIONS:

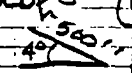
CASE I: WHAT IS SAFETY AGAINST TEARING UNDER GEOMEMBRANE'S OWN WEIGHT (IE COMPUTE LENGTH OF GEOMEMBRANE AT WHICH IT WOULD TEAR) - NO COVER

CASE II: WHAT IS SAFETY FACTOR AGAINST TEARING WITH 2 FT OF COVER SOIL AND AN INFINITELY LONG SLOPE?

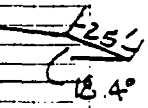
CASE III: WHAT IS RESISTANCE TO TEAR ALONG FINITE SLOPE?

ASSUMPTIONS/CONSIDERATIONS

- 40 MIL VLDPE GEOMEMBRANE - BOTH SMOOTH AND TEXTURED FABRICS WERE CONSIDERED FOR COMPARISON. TEXTURED VL IS NOT PROPOSED FOR THIS PROJECT.
- 2 FT OF COVER SOIL AT AVERAGE MOIST DENSITY OF 110 lb/CF (12" VEG. + 12" DRAINAGE SAND)
- DRY SLOPES
- CASE II ASSUME 500 LF SLOPE (WORST CASE) AT AN AVERAGE SLOPE OF 7% (4°)



- CASE III - 25 LF SIDESLOPE AT 3:1 (EDGE OF LANDFILL) - 18.4°



- CONSIDER 2 MANUFACTURERS OF VLDPE - NATIONAL SEAL (NSC) AND POLYFLEX

REFERENCES

1. "DESIGNING WITH GEOSYNTHETICS" KOERNER, R.M. 2nd Ed, 1990 CHAPT. 5

2. MNFCTRS LITERATURE

3. "LONG-TERM ALLOWABLE TENSILE STRESSES FOR POLYETHYLENE GEOMEMBRANES", RYAN BERG AND RUDOLPH BONAPARTE, GEOTEXTILES AND GEOMEMBRANES, 12 (1993) 287-306.

PROJECT	COMP. BY	JOB NO.
SULLIVAN LANDFILL TRW	KHL	6974-83
	CHK. BY	DATE
	LT	6/25/93

SUMMARY

CASE I NO COVER

	ANCHORED		SEAMED	
MNFCTR	LCRIT (FT)	FS/ROLL	LCRIT	FS/ROLL LENGTH
POLYFLEX				
SMOOTH	8400	14 (44)	–	–
NSC				
SMOOTH	9120	5.5 (17)	8208	4.1
TEX	5625	6	–	

CASE II - INFINITE SLOPE (7% SLOPE, 500 FT LONG)

	FS	
	SAND INTERFACE	CLAY INTERFACE
SMOOTH VLDPE	4.3	3.3
TEXTURED VLDPE	6.7	8.0

CASE III - FINITE SLOPE (3:1 SLOPE, 25 FT LONG)

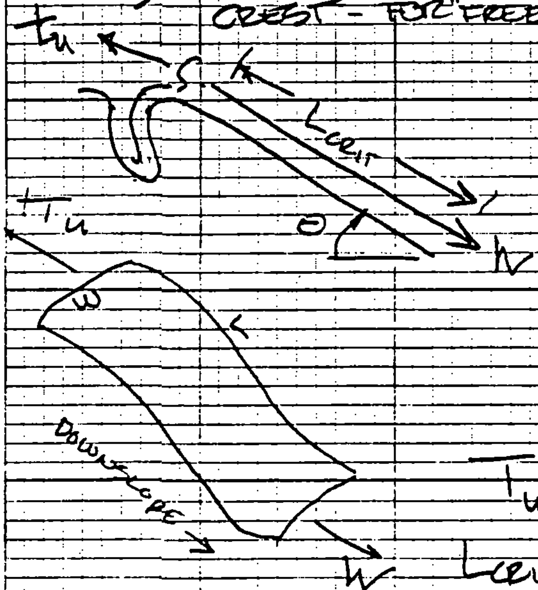
	FS				
	SAND INTERFACE			CLAY INTERFACE	
	@ 3:1	3½:1	4:1	@ 3:1	@ 4:1
SMOOTH VLDPE	1.8	2.1	2.4	1.6	2.1
TEXTURED VLDPE	1.7	2.0		2.0	—

PROJECT	COMP. BY	JOB NO.
SULLIVAN LANDFILL	KJA	697483
	CHK. BY	DATE
	LT	6/25/93

CASE I

- NO SOIL COVER
- DETERMINE CRITICAL LENGTH OF GEOMEMBRANE (L_{CRIT}) AT WHICH IT WOULD TEAR UNDER ITS OWN WT.
(NOTE THAT ROLL LENGTHS ARE LIMITED AS SHOWN ON TABLE 1) → DETERMINE FS FOR STANDARD ROLL LENGTH

a) ASSUME SINGLE RUN WITH ANCHOR TRENCH AT CREST - FOR "FREE-HANG" CONDITION (VERTICAL SLOPE)



W_{ROLL} POLYFLEX SMOOTH $= 2700$ lbs/ROLL / 600 LF (TBL 1)

$\omega' = 4.5$ lb/LF LENGTH

T_u = ULTIMATE TENSILE STRENGTH (AT BREAK)

t_u POLYFLEX $= 140$ lb/in WIDTH (TBL 1)

$T_u = 140\text{ lb} \times 22.5\text{ FT}\,(12''/\text{FT}) = 37800\text{ lbs}$

$L_{CRIT} = \dfrac{T_u}{\omega} = \dfrac{37800\text{ lb}}{4.5\text{ lb/LF}} = 8400\text{ LF}$ (FREE HANG = VERTICAL SLOPE - SEE PG 4 FOR 3:1 SLOPE CONDITION)

CHECK FS FOR ROLL LENGTH

$FS = \dfrac{T_u}{W_{ROLL}} = \dfrac{37800\text{ lb}}{2700} = \underline{\underline{14}}$

NSC

$W_{ROLL} = 5000$ lbs (TBL 1) $\quad \omega = \dfrac{5000}{1670\text{ LF}} = 3$ lb/LF

$t_u = 152\ \dfrac{\text{lb}}{\text{in}}$ (TBL 1)

$T_u = 152\text{ lb/in} \times 15'(12''/') = 27360\text{ lb}$

$L_{CRIT} = \dfrac{27360\text{ lb}}{3\text{ lb/ft}} = 9120\text{ LF} \qquad FS_{ROLL} = \dfrac{27360}{5000\text{ lb}} = \underline{\underline{5.5}}$

PROJECT: SULLIVAN LANDFILL

COMP. BY: KHL | JOB NO.: 697483

CHK. BY: LG | DATE: 6/25/93

IF USE TEXTURED 40 MIL VLDPE: (NSC DATA ONLY)

$W_{ROLL} = 3000 lb$

$t_u = 100\ lb/_{in\text{-}w}$ (TBL 1)

$T = 100(15')(12) = 18,000$

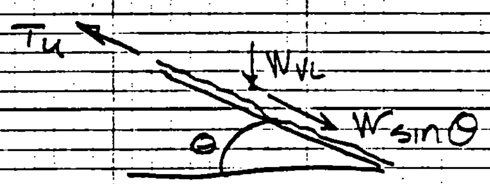
$FS_{ROLL\ LENGTH} = 18,000/3000 = 6$

$L_{CRIT} = \frac{T_u}{w}$ $\quad w = 3000 lb/950 = 3.2\ lb/FT$

$L_{CRIT} = \frac{18000 lb}{3.2} = 5625\ FT$

ALTERNATE ANALYSIS:

IF CONSIDER SLOPE OF FABRIC PLACEMENT:



$\theta_{MAX} = 3:1 = 18.4°$

$\theta_{MIN} = 7\% = 4°$

NSC

$T_{u\ MD\ (NSC)} = 27360\ lb/FT$

$W_{VL} = 3\ lb/FT$

$W \sin\theta = 3 \sin 18.4°$

$= 0.95\ lb/FT$

$L_{CRIT} = \frac{27360}{0.95} = 28,800\ lb/FT$

$FS_{PER\ ROLL\ (NSC)} = \frac{27360\ lb/FT}{5000 \sin 18.4} = \underline{\underline{17.3}}$

POLYFELX

$T_{u\ FF} = 37800\ lb/FT$

$W_{PER\ ROLL} = 2700 lb$

$FS = \frac{37800 lb/FT}{2700 \sin 18.4}$

$FS = \underline{\underline{44}}$

∴ PREVIOUS ANALYSIS IS MORE CONSERVATIVE

FORM 00.01 REV. 4/81

ABB Environmental Services, Inc.

PROJECT	COMP. BY	JOB NO.
SULLIVAN LANDFILL	KHC	6974.83
	CHK. BY	DATE
	LV	6/25/93

b) ASSUME HDPE IS SEAMED ∴ t_u SEAM GOVERNS

POLYFLEX (SMOOTH) $t_{u_{SEAM}} = 35$ lb/in (YIELD STRENGTH NOT BREAK STRENGTH)

$T_u = 35\,lb/in \times 22.5(12) = 9450$ lbs

$L_{CRIT} = \frac{9450}{4.5\,lb/LF} = 2100$ LF

$FS_{ROLL} = \frac{9450\,lb}{2700} = 3.5$

NSC (SMOOTH) $t_{u_{SEAM}} = 48$ lb/in $T_u = 48(15)(12') = 8640$ lb

$L_{CRIT} = \frac{8640\,lb}{3\,lb/FT} = 2880$ LF

$FS_{ROLL} = \frac{8640\,lb}{5000} = 1.73$

THESE NUMBERS ARE ACTUALLY THE SAFETY FACTOR AND LCRIT AT WHICH THE SEAM WOULD YIELD (STRETCH)

SUBSEQUENT TEL COMMUNICATION WITH NSC SALES REP INDICATED THAT THEY DO NOT HAVE BREAK STRENGTH DATA ON SEAMS. HE SAID SEAMS ARE TYPICALLY 90% STRENGTH OF PARENT ∴

NSC: $0.9\,T_u = 0.9(27360) = 24624$ lb/FT

$L_{CRIT} = 24624 / 3\,lb/FT = 8208$ LF

$FS = \frac{24624}{5000\,lb} = 5$

IF $.75\,T_u \Rightarrow 20520$

$FS = \frac{20520}{5000} = 4.1$ ok

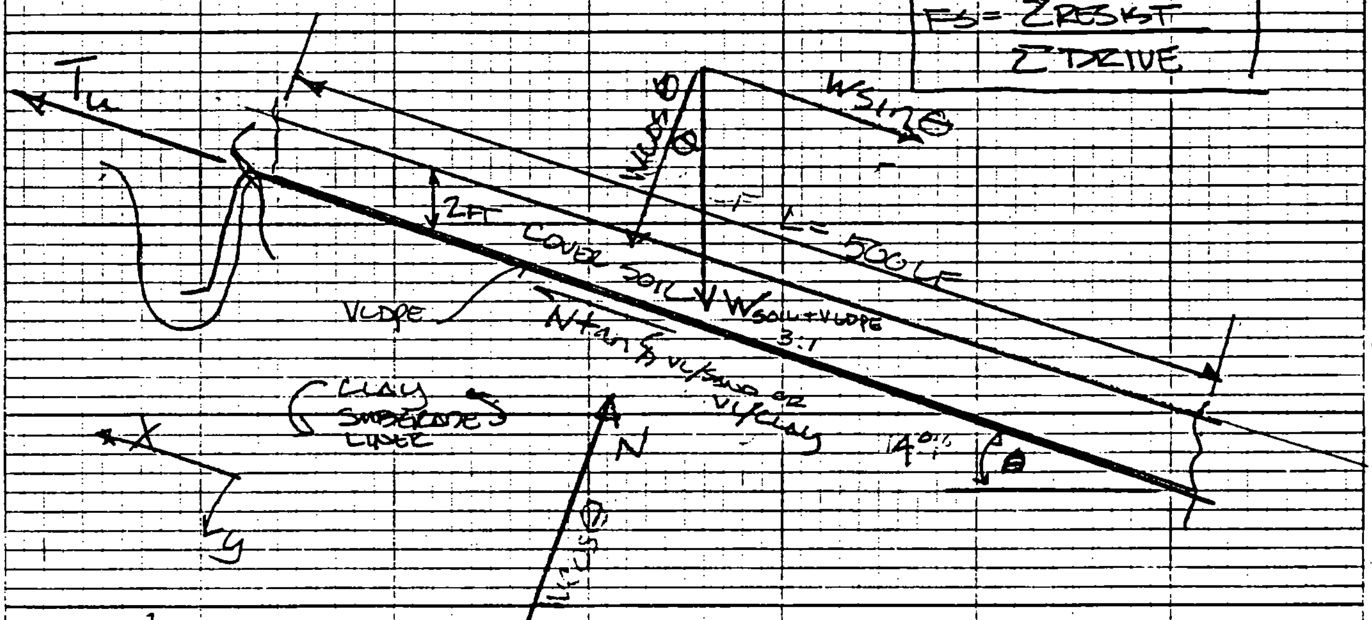
PROJECT	COMP. BY	JOB NO.
SULLIVAN LANDFILL	KHL	697493
	CHK. BY: LO	DATE: 6/25/93

CASE II

— FOR A 500 LF LONG SLOPE AT AVERAGE SLOPE 7% AND 2 FT OF COVER, WHAT IS FS AGAINST TEAR?

— LOGIC AT BOTH SAND/VLDPE AND VLDPE/CLAY INTERFACES FOR SMOOTH AND TEXTURED FABRIC.

$\boxed{FS = \frac{\Sigma RESIST}{\Sigma DRIVE}}$



SAND/VLDPE WITH TEXTURED FABRIC

$W = 500\ LF\ (2FT)(110\ PCF) = 110{,}000\ lb/FT$

USE $\delta = 25°$ (TBL 1)

$W_{VLDPE} = (0.2 PSF) \times (500 LF) = 100\ lb/FT$ (Tbl 1) N/C

$W_{TEX} \approx W_{SMOOTH}$

$\Sigma RESIST = T_u + N\tan\delta$

$\Sigma DRIVE = W_{SOIL}\sin\theta + W_{VLDPE}\sin\theta$

$N\tan\delta = W\cos\theta\tan\delta$

$= 110{,}100\ lb/_{FT}\ \cos 4° \tan 25° = 51215\ lb/_{FT}$

$\Sigma DRIVE = 110{,}000 \sin 4° + 100 \sin 4° = 7680\ lb/_{FT}$

$T_u = 45\ lb/_{in} \times 12\ in/_{FT} = 540\ lb/$ FT OF WIDTH

TEXT POLYFLEX (TBL 1)

$\Sigma RESIST = 540\ lb/_{FT} + 51215\ lb/_{FT} = 51755\ lb/_{FT}$

FORM 00.01 REV. 4/81 ABB Environmental Services, Inc.

PROJECT	COMP. BY	JOB NO.
SULLIVAN LF CASE II	KHC	6974-83
	CHK. BY LJ	DATE 4/26/93

$\Sigma DRIVE = 7680\ lb/FT$

$FS = \frac{51755\ lb/FT}{7680\ lb/FT} = \boxed{6.7}$

CHECK SLIDING

$FS = \frac{TAN\ \delta}{TAN\ \theta} = \frac{TAN\ 25}{TAN\ 4} = 6.7$ OK

SMOOTH VLDPE, SAND/VL INTERFACE

$\delta = 16°$ $\quad t_u = 140\ lb/IN \times 12 = 1680\ lb/FT$

$\Sigma RESIST = 110,000 \cos 4 \tan 16° + 1680 = 33145\ lb/FT$

$\Sigma DRIVE = 7680\ lb/FT$

$FS = 33145/7680 = \boxed{4.3}$

$FS_{SLID} = \frac{TAN\ 16}{TAN\ 4} = 4.1$ OK

CLAY/VLDPE WITH TEXTURED FABRIC

$\delta_{VL/CLAY\ (TEXT)\ NSC} = 29°$

$W_{VL} = 100\ lb/FT\ (WIDTH)$ (pg 5)

$W_{SOIL} = 110,000\ lb/FT$ (pg 5)

$\Sigma DRIVE = (W_{SOIL} + W_{VL}) \sin \theta$

$\Sigma DRIVE = 7680\ lb/FT$ (pg 5)

$\Sigma RESIST = T_u + N \tan \delta$

$\Sigma R = 110,100\ lb/FT \cos 4° \tan 29 + \overset{T_u\ text}{540\ lb/FT} = 61421\ lb/FT$

$FS = \frac{61421}{7680} = \boxed{8.0}$

$FS_{SLID} = \frac{TAN\ 29}{TAN\ 4} = 7.3$ ok

WITH SMOOTH VL: $\delta = 12°$

$\Sigma DRIVE = 7680\ lb/FT$

$\Sigma RESIST = 110,100 \cos 4 \tan 12 + \overset{T_{u\ smooth}}{1680\ lb/FT} = 25025\ lb/FT$

$FS = \frac{25025}{7680} = \boxed{3.3}$

SLIDING STABILITY

$FS_{SLID} = \frac{TAN\ \delta}{TAN\ \theta}$ (ROUGH APPROXIMATION) WORST CASE - CLAY

$\delta_{min} = 12°$ $\quad \theta = 4°$

$\frac{TAN\ 12}{TAN\ 4} = 3.0$ OK

PROJECT	COMP. BY	JOB NO.
SULLIVAN LF TRW	KH	6974 83
	CHK. BY LG	DATE 6/25/93

CASE III

SIMILAR TO CASE II EXCEPT $\theta = 3:1\ (18.4°)$ AND $L = 25$ FT

- LOOK AT SAND/VL AND CLAY/VL INTERFACE FOR BOTH SMOOTH AND TEXTURED FABRIC

SAND/VL INTERFACE, SMOOTH GEOMEMBRANE

$$FS = \frac{\Sigma RESIST}{\Sigma DRIVE} = \frac{T_u + N \tan\delta}{(W_{soil} + W_{VL})\sin\theta}$$

$N = (W_{soil} + W_{VL})\cos\theta$

$\delta = 16°$

$$N = \left[\overbrace{\underbrace{(25')(2\ FT)(110)}_{XLE} + (\underbrace{0.21}_{\sigma_{VL}} lb/_{SF})(25')}^{5505}\right]\cos 18.4°$$

$N = 5224$ lb/FT

$T_u = 1080$ lb/FT (pg 6)

$\Sigma R = 5224 \tan 16° + 1080 = 3178$ lb/FT

$\Sigma DRIVE = 5505 \sin 18.4° = 1738$ lb/FT

$FS = 3178/1738 = \boxed{1.8}$

FOR FS = 2.0 SOLVE FOR θ

$$2.0 = \frac{5505\cos\theta\tan 16 + 1080}{5505 \sin\theta}$$

$\theta = 14°\ (4:1) = 2.4$

$\theta = 16°\ (3.5:1) = 2.1$

$\boxed{\theta = 3\tfrac{1}{2}:1 \Rightarrow FS = 2.1}$

SAND/VL, TEXTURED GEOMEMBRANE

$\delta = 25°$ (TBL 1)

$T_u = 540$ lb/FT (pg 6)

$\Sigma RESIST = 5224 \tan 25 + 540 = 2976$ lb/FT

$\Sigma DRIVE = 1738$ lb/FT

$FS = 2976/1738 = \boxed{1.7}$

PROJECT	COMP. BY	JOB NO.
SULLIVAN LANDFILL	KHC	697483
	CHK. BY	DATE
	LX	6/26/93

FOR FS ≈ 2.0 SOLVE FOR Θ

TRY $3\frac{1}{2}:1 = 16°$ $\quad FS = \dfrac{5505 \cos\Theta \tan 25 + 540}{5505 \sin\Theta}$

$\boxed{FS = 2.0}$

CLAY / VL INTERFACE, SMOOTH GEOMEMBRANE

$\delta_{VL/CLAY\ SMOOTH} = 12°$

Σ DRIVE = 1738 lb/FT   pg 8 FOR SMOOTH VL

Σ RESIST = 5224 tan 12° + 1680 lb/FT = 2790 lb/FT

$FS = 2790/1738 = \boxed{1.60}$

FOR FS ≈ 2.0 SOLVE FOR Θ

$FS = \dfrac{5505 \cos\Theta \tan 12 + 1680}{5505 \sin\Theta}$

$\Theta = 16° \rightarrow FS = 1.85$

$\Theta = 14°$ $\boxed{FS = 2.1}$

4:1

PROJECT SULLIVAN LANDFILL

COMP. BY KHC

CHK. BY [illegible]

JOB NO. 6974-83

DATE 6/25/93

CLAY VL, TEXTURED GEOMEMBRANE

$\delta_{VL} = 29^\circ$ (TBL 1)

$\tau_u = 540$ lb/FT (pg 5)

Σ RESIST = 5224 tan 29 + 540 = 3436 lb/FT

Σ DRIVE = 1738 lb/FT

FS = 3436/1738 = 1.97 ~ 2.0 ok

FORM 00.01 REV. 4/81

ABB Environmental Services, Inc.

PROJECT	COMP. BY	JOB NO.
TABLE 1 40 MIL VLDPE PROPERTIES	KHL	69748 3
	CHK. BY	DATE
	[illegible]	6/25/93

	ROLL WT	LENGTH	WIDTH	TENSILE AT BREAK	SEAM STRENGTH	δ (°) SAND	δ (°) CLAY
POLYFLEX	(.2 lb/SF)						
SMOOTH	2700 lb	600 LF	22.5	140 lb/in	35 lb/in ?	16-18*	12-15
TEXTURED	(NA)	450	22.5	45 lb/in		25 ?	?
NSC							
SMOOTH	(.2 lb/SF) 5000	1070	15	152	48	16-18*	12-15
TEXT	3000 (0.2 lb/SF)	950	15	100		37	29

NA = NOT AVAILABLE

* INDUSTRY AVERAGE FOR HDPE - NON-SPECIFIC MFCTR (KOERNER)

** ADHESION NOT INCLUDED

NSC

40 mil VLDPE GEOMEMBRANE QUALITY CONTROL SPECIFICATIONS

National Seal Company's Polyethylene Geomembranes are produced from virgin, first quality, high molecular weight resins and are manufactured specifically for containment in hydraulic structures. NSC geomembranes have been formulated to be chemically resistant, free of leachable additives and resistant to ultraviolet degradation.

The following properties are tested as a part of NSC's quality control program. Certified test results for properties on this page are available upon request. Refer to NSC's Quality Control Manual for exact test methods and frequencies.

RESIN PROPERTIES	METHOD	UNITS	MINIMUM[1]	TYPICAL
Melt Flow Index[2]	ASTM D 1238	g/10 min	0.50	0.25
Density[2]	ASTM D 1505	g/cm^3	0.915	0.909
SHEET PROPERTIES	**METHOD**	**UNITS**	**MINIMUM[1]**	**TYPICAL**
Thickness	ASTM D 751, NSF mod.			
Average		mils	40.0	41.5
Individual		mils	38.0	40.3
Density[2]	ASTM D 1505	g/cm^3	0.930	0.922
Carbon Black Content	ASTM D 1603	percent	2.0-3.0	2.6
Carbon Black Dispersion	ASTM D 3015, NSF mod.	rating	A1, A2, B1	A1
Tensile Properties	ASTM D 638			
Stress at Break		psi	3800	4820
		ppi	152	200
Strain at Break	2.0" gage length	percent	850	1050
	2.5" gage length (NSF)	percent	680	840
Dimensional Stability[2]	ASTM D 1204, NSF mod.	percent	3.0	1.9
Tear Resistance	ASTM D 1004	ppi	550	600
		lbs	22	25
Puncture Resistance	ASTM D 4833	ppi	1500	2120
		lbs	60	88
Oxidative Induction Time	ASTM D 3895, Al pan, 200°C, 1 atm O_2	minutes	75	100

[1] This value represents the minimum acceptable test value for a roll as tested according to NSC's Manufacturing Quality Control Manual. Individual test specimen values are not addressed in this specification except thickness.

[2] Indicates Maximum Value

40 mil VLDPE GEOMEMBRANE
PHYSICAL PROPERTIES

The properties on this page are not part of NSC's Manufacturing Quality Control program and are not included on the material certifications. Seam testing is the responsibility of the installer and/or CQA personnel.

PROPERTIES	METHOD	UNITS	MINIMUM[1]	TYPICAL
Multi-Axial Tensile Elongation	GRI, GM-4	percent	75.0	110.0
Critical Cone Height	GRI, GM-3, NSC mod.	cm	6.0	6.5
Brittleness Temp. by Impact[2]	ASTM D 746	°C	-75	<-90
Coef. of Liner Thermal Exp.[2]	ASTM D 696	$°C^{-1}$	$3.0x10^{-4}$	$2.4x10^{-4}$
Hydrostatic Resistance	ASTM D 751	psi	130	160
2% Secant Modulus[2]	ASTM D 638	psi	35,000	13,700
Ozone Resistance	ASTM D 1149, 168 hrs	P/F	P	P
Permeability[2]	ASTM E 96	cm/sec · Pa	2.8×10^{-13}	2.2×10^{-13}
Puncture Resistance	FTMS 101, method 2065	ppi	1400	2260
		lbs	56	94
Soil Burial Resistance[2]	ASTM D 3083, NSF mod.	% change	10	0
Tensile Impact	ASTM D 1822	ft lbs/in^2	1330	1560
Volatile Loss[2]	ASTM D 1203, A	percent	0.13	0.11
Water Absorption[2]	ASTM D 570, 23°C	percent	0.10	0.06
Water Vapor Transmission[2]	ASTM E 96	g/day · m^2	0.294	0.232

SEAM PROPERTIES	METHOD	UNITS	MINIMUM[1]	TYPICAL
Shear Strength	ASTM D 4437, NSF mod.	psi	1200	1300
	20 ipm	ppi	48	54
Peel Strength	ASTM D 4437, NSF mod.	psi	1000	1300
	20 ipm	ppi	40	54

STANDARD ROLL DIMENSIONS

Length	1670 feet	Area	25,050 ft^2
Width	15 feet	Weight	5,000 lbs

textured membrane

40 mil FRICTION SEAL VL GEOMEMBRANE
QUALITY CONTROL SPECIFICATIONS

National Seal Company's Polyethylene Geomembranes are produced from virgin, first quality, high molecular weight resins and are manufactured specifically for containment in hydraulic structures. NSC geomembranes have been formulated to be chemically resistant, free of leachable additives and resistant to ultraviolet degradation.

The following properties are tested as a part of NSC's quality control program. Certified test results for properties on this page are available upon request. Refer to NSC's Quality Control Manual for exact test methods and frequencies.

RESIN PROPERTIES	METHOD	UNITS	MINIMUM[1]	TYPICAL
Melt Flow Index[2]	ASTM D 1238	g/10 min	0.50	0.25

SHEET PROPERTIES	METHOD	UNITS	MINIMUM[1]	TYPICAL
Mass per Unit Area[3]	ASTM D 3776	lb/ft^2	0.21	0.22
Thickness[4]	ASTM D 751, NSF mod.			
Average		mils	40.0	41.5
Individual		mils	38.0	40.3
Density[4]	ASTM D 1505	g/cm^3	0.930	0.922
Carbon Black Content[4]	ASTM D 1603	percent	2.0-3.0	2.6
Carbon Black Dispersion[4]	ASTM D 3015, NSF mod.	rating	A1, A2, B1	A1
Tensile Properties[5]	ASTM D 638			
Stress at Break		psi	2500	3495
		ppi	100	145
Strain at Break	2.0" gage length	percent	400	670
	2.5" gage length (NSF)	percent	320	536
Dimensional Stability[4]	ASTM D 1204, NSF mod.	percent	3.0	1.9
Tear Resistance	ASTM D 1004	ppi	550	760
		lbs	22	32
Puncture Resistance[4]	ASTM D 4833	ppi	1500	2120
		lbs	60	88
Friction Angle, Index	GRI, GS-7	degrees	40	56
Oxidative Induction Time	ASTM D 3895, Al pan, 200°C, 1 atm O_2	minutes	75	100

[1] This value represents the minimum acceptable test value for a roll as tested according to NSC's Manufacturing Quality Control Manual. Individual test specimen values are not addressed in this specification except thickness.

[2] Indicates Maximum Value

[3] Friction Coating on both sides of base sheet

[4] Testing performed on base sheet

[5] Stress and strength values are normalized to the nominal base sheet thickness. NSC certifies properties based on values calculated using nominal thickness only. Stress values calculated using actual product thickness is not guaranteed due to the lack of industry accepted thickness test procedures for friction sheet.

40 mil FRICTION SEAL VL GEOMEMBRANE
PHYSICAL PROPERTIES

The properties on this page are not part of NSC's Manufacturing Quality Control program and are not included on the material certifications. Seam testing is the responsibility of the installer and/or CQC personnel.

PROPERTIES	METHOD	UNITS	MINIMUM[1]	TYPICAL
Multi-Axial Tensile Elongation	GRI, GM-4	percent	40.0	57.0
Critical Cone Height	GRI, GM-3, NSC mod.	cm	5.0	5.5
Brittleness Temp. by Impact[2]	ASTM D 746	°C	-75	<-90
Coef. of Linear Thermal Exp.[2]	ASTM D 696	$°C^{-1}$	3.0×10^{-4}	2.4×10^{-4}
Hydrostatic Resistance[4]	ASTM D 751	psi	150	180
2% Secant Modulus[2,4]	ASTM D 638	psi	35,000	13,700
Ozone Resistance[4]	ASTM D 1149, 168 hrs	P/F	P	P
Permeability[2,4]	ASTM E 96	cm/sec · Pa	2.8×10^{-13}	2.2×10^{-13}
Puncture Resistance	FTMS 101, method 2065	ppi	1400	1760
		lbs	56	73
Soil Burial Resistance[2]	ASTM D 3083, NSF mod.	% change	10	0
Tensile Impact	ASTM D 1822	ft lbs/in^2	1330	1560
Volatile Loss[2,4]	ASTM D 1203, A	percent	0.13	0.11
Water Absorption[2,4]	ASTM D 570, 23°C	percent	0.10	0.06
Water Vapor Transmission[2,4]	ASTM E 96	$g/day \cdot m^2$	0.294	0.232

SEAM PROPERTIES	METHOD	UNITS	MINIMUM[1]	TYPICAL
Shear Strength	ASTM D 4437, NSF mod.	psi	1200	1300
	20 ipm	ppi	48	54
Peel Strength	ASTM D 4437, NSF mod.	psi	1000	1300
	20 ipm	ppi	40	54

STANDARD ROLL DIMENSIONS

Length	950 feet	Area	14,250 ft^2
Width	15 feet	Weight	3,000 lbs

This information contained herein has been compiled by National Seal Company and is, to the best of our knowledge, true and accurate. All suggestions and recommendations are offered without guarantee. Final determination of suitability for use based on any information provided, is the sole responsibility of the user. There is no implied or expressed warranty of merchantability of fitness of the product for the contemplated use.

NSC reserves the right to update the information contained herein in accordance with technological advances in the material properties.

POLY-FLEX
POLYETHYLENE GEOMEMBRANES

DURA-FLEX VLDPE SPECIFICATIONS

Typical Properties

		Typical Value*			
Property	Test Method	20 mil (0.5mm)	30 mil (0.75mm)	40 mil (1.0mm)	60 mil (1.5mm)
Thickness, mils, minimum	ASTM D 1593	18	27	36	54
Density (g/cc), maximum	ASTM D 1505	0.935	0.935	0.935	0.935
Melt Index (g/10 min., maximum)	ASTM D 1238	0.6	0.6	0.6	0.6
Carbon Black content (%)	ASTM D 1603	2 -3	2 -3	2 -3	2 -3
Carbon Black Dispersion	ASTM D 3015	A-1, A-2, B-1	A-1, A-2, B-1	A-1, A-2, B-1	A-1, A-2, B-1
Tensile Properties	ASTM D 638				
1. Ultimate Tensile Strength (pounds/inch width)	Type IV specimen at 20 inches/minute	75	110	140	210
2. Ultimate Elongation (%)		1000	1000	1000	1000
3. Modulus of Elasticity (secant modulus; pounds/square inch)		15,000	15,000	15,000	15,000
Tear Strength (lbs.)	ASTM D 1004 Die C	9	14	17	28
Puncture Resistance (lbs.)	**FTMS 101 C 2065	30	45	55	80
Low Temperature Brittleness	ASTM D 746	<-94° F	<-94° F	<-94° F	<-94° F
Dimensional Stability (% change max.)	ASTM D 1204 212° F, 15 min.	± 3	± 3	± 3	± 3
Resistance to Soil Burial (% change max. in orig. value)	ASTM D 3083 type IV specimen				
A. Ultimate Tensile Strength	at 20 inches/minute	10	10	10	10
B. Ultimate Elongation		10	10	10	10
Environmental Stress Crack (hours)	ASTM D 1693 Condition C (modified NSF 54)	>2000	>2000	>2000	>2000
Field Seam Properties					
1. Shear Strength (pounds/inch), min.	ASTM D 3083 (modified NSF 54)	20 (or 12" elong.)	32 (or 12" elong.)	35 (or 12" elong.)	72 (or 12" elong.)
2. Peel Strength (pounds/inch), min.	ASTM D 413 (modified NSF 54)	20 FTB†	32 FTB	35 FTB	72 FTB
Roll Dimensions					
1. Width (feet):		22.5	22.5	22.5	22.5
2. Length (feet):		1000	800	600	400
3. Area (square feet):		22,500	18,000	13,500	9000
4. Weight (pounds, approx.):		2250	2700	2700	2700

* All values, except when specified as minimum or maximum, represent average lot property values.
** Federal Test Method Standards.
† Film Tear Bond (FTB) is defined as failure of one of the sheets by tearing, instead of separating from the other sheet at the weld interface area (sheet fails before weld).

POLY-FLEX
POLYETHYLENE GEOMEMBRANES

DURA-FLEX VLDPE SPECIFICATIONS

Typical Properties: 40 mil.

Property	Test Method	Test Results*
Thickness, mils, minimum	ASTM D 1593	36
Density (g/cc), maximum	ASTM D 1505	0.935
Melt Index (g/10 min., maximum)	ASTM D 1238	0.6
Carbon Black content (%)	ASTM D 1603	2 -3
Carbon Black Dispersion	ASTM D 3015	A-1, A-2, B-1
Tensile Properties	ASTM D 638	
1. Ultimate Tensile Strength (pounds/inch width)	Type IV specimen at 20 inches/minute	140
2. Ultimate Elongation (%)		1000
3. Modulus of Elasticity (secant modulus; pounds/square inch)		15,000
Tear Strength (lbs.)	ASTM D 1004 Die C	17
Puncture Resistance (lbs.)	**FTMS 101 C 2065	55
Low Temperature Brittleness	ASTM D 746	<-94° F
Dimensional Stability (% change max.)	ASTM D 1204 212° F, 15 min.	± 3
Resistance to Soil Burial (% change max. in orig. value)	ASTM D 3083 type IV specimen at 20 inches/minute	
A. Ultimate Tensile Strength		10
B. Ultimate Elongation		10
Environmental Stress Crack (hours)	ASTM D 1693 Condition C (modified NSF 54)	>2000
Field Seam Properties		
1. Shear Strength (pounds/inch), min.	ASTM D 3083 (modified NSF 54)	35 (or 12" elong.)
2. Peel Strength (pounds/inch), min.	ASTM D 413 (modified NSF 54)	35 FTB†

* All values, except when specified as minimum or maximum, represent average lot property values.
** Federal Test Method Standards.
† Film Tear Bond (FTB) is defined as failure of one of the sheets by tearing, instead of separating from the other sheet at the weld interface area (sheet fails before weld).

Polyflex

Friction Characteristics

Creating a stable liner system requires an analysis of the static and dynamic loads and their effect on the stability of the liner system during and after its installation. Designers should provide adequate factors of safety to prevent the following problems that can occur to a liner system on slopes:

- Cover soils sliding downhill on the liner.
- Liner or other synthetic components pulling out of the anchor trench due to weight of the cover or dynamic load of machinery.
- Tension in the liner or other components of the liner system due to weight of the cover, gradually leading to the system's failure.

Poly•Flex Roughened HDPE-R and VLDPE-R are specifically manufactured with surface roughness to create a higher interface friction than the smooth liners when in contact with soils or other geosynthetic material. The higher friction enhances stability on steep slopes.

Independent laboratory test reports, evaluating the interface friction values of Poly•Flex HDPE-R and VLDP E-R next to soils and other geosynthetic materials, are summarized in the Table below.

The following friction test results are for general information purposes. Test materials and conditions may not represent the corresponding materials and conditions of your project. Therefore, we strongly recommend that interface friction tests for your projects be performed by reputable testing laboratories. These tests should be done under site-specific conditions for all liner system interfaces. Please contact Poly•Flex. Inc. for further information on interface friction testing.

Test Apparatus: 12" x 12" Shear Box
Normal Stress: 5, 10, 15 psi for HDPE-R tests
3. 6, 9 psi for VLDPE-R tests

TEST CONDITION	COEFFICIENT OF FRICTION	FRICTION ANGLE	ADHESION PSI
SITE *			
HDPE-R/Concrete Sand	0.58 (86%)	30°	0
HDPE-R/Kaolinite Clay	0.19 (100%)	11°	0.3 (100%)
SITE §			
HDPE-R/Ottawa Sand	0.78 (100%)	38°	0
HDPE-R/Composite Net	0.58 P	30° P	0.7 P
	0.34 R	19° R	0.5 R
HDPE-R/Geotextile	0.49	26°	1.2
VLDPE-R/Ottawa Sand	0.47	25°	1.2
VLDPE-R/Composite Net	0.47	25°	1.2
VLDPE-R/Geotextile	0.47	25°	0.6

* - Geosynthetic Research Institute
§ - Westinghouse Environmental and Geotechnical Services. Inc.
P - Peak
R - Residual
( )- Friction Efficiency = $(\tan\delta/\tan\phi)$ 100%
Cohesion Efficiency = (c/c_a) 100%

Poly-Flex Roughened HDPE Geomembrane

PROPERTY	TEST METHOD	NOMINAL VALUE*			
Thickness (mils)	ASTM D 1593	40	50	60	80
Melt index, (g/10 min), max.	ASTM D 1238	0.4	0.4	0.4	0.4
Carbon Black Content (%)	ASTM D 1603	2-3	2-3	2-3	2-3
Carbon Black Dispersion	ASTM D 3015	A-1, A-2, B-1	A-1, A-2, B-1	A-1, A-2, B-1	A-1, A-2, B-1
Tensile Properties:	ASTM D 638 Type IV Specimen				
Yield Strength (lbs/in)		85	105	126	170
Break Strenth (lbs/in)		25	30	35	58
Yield Elongation (%)		13	13	13	13
Break Elongation (%)		100	100	100	100
Tear Strength (lbs)	ASTM D 1004	30	37	45	60
Puncture Resistance (lbs)	FTMS 101C-2065	45	57	70	95
Low Temperature Brittleness	ASTM D 748	<-94° F	<-94° F	<-94° F	<-94° F
Dimensional Stability	ASTM D 1204	± 1.0%	± 1.0%	± 1.0%	± 1.0%
Environmental Stress Crack Resistance (hrs)	ASTM D 1693 Condition B	>2000	>2000	>2000	>2000
Roll Dimension					
1. Width (ft)		22.5	22.5	22.5	22.5
2. Length (ft)		450	400	350	250

Poly-Flex Roughened VLDPE Geomembrane

PROPERTY	TEST METHOD	NOMINAL VALUE*		
Thickness (mils)	ASTM D 1593	40	50	60
Melt index, (g/10 min), max.	ASTM D 1238	0.7	0.7	0.7
Carbon Black Content (%)	ASTM D 1603	2-3	2-3	2-3
Carbon Black Dispersion	ASTM D 3015	A-1, A-2, B-1	A-1, A-2, B-1	A-1, A-2, B-1
Tensile Properties:	ASTM D 638 Type IV Specimen			
Break Strenth (lbs/in)		45	58	70
Break Elongation (%)		300	300	300
Tear Strength (lbs)	ASTM D 1004	13	16	20
Puncture Resistance (lbs)	FTMS 101C-2065	30	37	45
Low Temperature Brittleness	ASTM D 748	<-94° F	<-94° F	<-94° F
Dimensional Stability	ASTM D 1204	± 3%	± 3%	± 3%
Environmental Stress Crack Resistance (hrs)	ASTM D 1693 Condition B	>2000	>2000	>2000
Roll Dimension				
1. Width (ft)		22.5	22.5	22.5
2. Length (ft)		450	400	350

* All values, except when specified as minimum or maximum, represent average lot values.